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Development of a Video Image-Based Methodology for Estimating Large Scale Transient Hydrocarbon Smoke Plume Size and Extent

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Development of a Video Image-based Methodology for Estimating Large Scale Hydrocarbon Smoke Plume Size and Extent

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Abstract

Interest in burning crude oil as a means to mitigate large scale oil spills at sea led to mid-scale evaluation of relevant crude oil burning characteristics. As part of this effort, a computer-based field measurement technique for estimating the size, shape, and extent of visible smoke plumes was developed. Of the experiments in which measurements were made, Test 7 provided data on plume trajectory for the largest distance from the pan. Good agreement was obtained between corresponding 35 mm photographs and digitized images used to estimate plume volume and trajectory. In Test 7, at 600 s after ignition, the leading edge of the smoke plume had risen to 780 m and traveled 1800 m downwind from the pan. The estimated total volume of the smoke plume at 600 s after ignition was 3.8×10^8 m^3. At that time, the total volume of the smoke plume was increasing at a rate of 3.2×10^6 m^3/s. Limited evaluation indicates that the MS-DOS based method provides reasonably accurate estimates of visible smoke plume geometry in the near-field. Field accuracy depends on plume size, wind speed and direction, and the resolution of the equipment.

Key Words:

crude oil
discrete pattern recognition
smoke plumes
computer program
fire tests
digital imaging
MS-DOS compatible

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1.0 INTRODUCTION

1.1 General

Recent oil spills, such as the Exxon Valdez in Alaska, have increased the public's awareness of the damage done to the environment by such accidents. One of the critical factors in equating the amount of damage done to the environment has been the spill response method used to clean up the oil. In the case of the Exxon Valdez, the main spill response method was containment of the oil spill with booms and the use of skimmers to recover the oil from the water surface. This method proved futile when weather conditions such as high winds and rough sea conditions prevailed. An alternative but somewhat controversial practice involves burning the oil spill, thus reducing the threat of damage to marine life and contamination of the water. A major limitation to burning oil at sea is that as the oil spreads on the water, the sea acts as a very effective heat sink. Therefore, it is difficult to raise the temperature of the thin layer of oil high enough to achieve ignition.

The process of burning crude oil on water as a means to mitigate oil spills has been investigated and researched by the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) for the United States Minerals Management Service (MMS), the United States Coast Guard (USCG), and the American Petroleum Institute (API) [1-4]. Through the use of small scale experiments and calculations, these studies have increased the understanding of the burning process of crude oil on water. These studies have included investigation of the burning rate, fire radiation, smoke emission, smoke composition and smoke dispersion in the atmosphere. The burning of oil as a spill response method has shown positive results at the small scale level by NIST. However, these favorable results must be replicated under large scale field conditions in order to gain acceptance as a spill response method by local officials and oil spill response professionals.

In response to this need, a series of intermediate or mid-scale field tests was conducted in Mobile, Alabama at the U.S. Coast Guard Fire and Safety Detachment facility. The objective of these tests was to provide data on smoke composition, soot yield, smoke concentration, thermal radiation, oil and water temperature, residual oil quantities, and smoke plume optical density, volume and position. The results from these experiments are being used to quantify the combustion efficiency and the potential environmental impact of burning crude oil as a means to mitigate oil spills.

1.2 Scope and Objectives

One of the tasks associated with the "mid-scale" field test effort involved development of a computer program and related field measurement/imaging techniques to analyze individual test records and provide estimates of smoke plume volumes and position. This task was assigned to the Naval Research Laboratory (NRL) under contract from the National Institute of Standards and Technology (NIST).

Specific objectives associated with this task included the following:

(1) development of a computer based methodology for analyzing images of smoke plumes;

(2) design of a video based field test scheme(s) to obtain plume images;

(3) evaluation/modification of the field test scheme during the mid-scale field tests; and

(4) preliminary review of the feasibility of adapting commercially available atmospheric dispersion models to prediction of smoke plume volume and extent.

1.3 Approach

1.3.1 General

Two methods, discrete pattern recognition and spectral signature analysis, appeared to have applicability to this problem. Discrete pattern recognition is the most widely developed technique, adapting technologies such as gray band discrimination and radar signature. The most attractive features associated with this approach include the portability and relatively modest cost of field equipment, and the availability of support hardware and software for analyzing, storing, and retrieving the test results, and manipulation and presentation of the data. However, there are several potential limitations associated with this approach. The most important limitation may lie in the accuracy of the field measurements. Several sources of error exist due to the lack of uniform plume shape, the distances associated with the required field of view, and the difficulty in discriminating between clouds and smoke. Another limitation is associated with the difficulties of plume edge discrimination, which may necessitate an interactive step on the part of the user during analysis of the measurements. This step could be computerized at a later time depending on an evaluation of the error introduced in incorporating gray band discrimination in the analysis software.

Spectral signature analysis is under development and has been successfully field tested on a limited scale for applications such as sky-cloud discrimination. Typical output, however, is limited to the percent cloud cover rather than quantitative measures of size, volume, and position. It appears that the use of this technique, based on physical optics of light scattering (e.g., Rayleigh and Mie scattering), could provide a more accurate discrimination among sky, clouds, and smoke. However, considerable development time would be required to isolate appropriate color separation filters and test their ability relative to distinction between optical light effects from clouds and smoke plumes of varying densities. In addition, each measurement station would require at least three cameras, considerably complicating the field testing.

1.3.2 Digital Imaging and Analysis

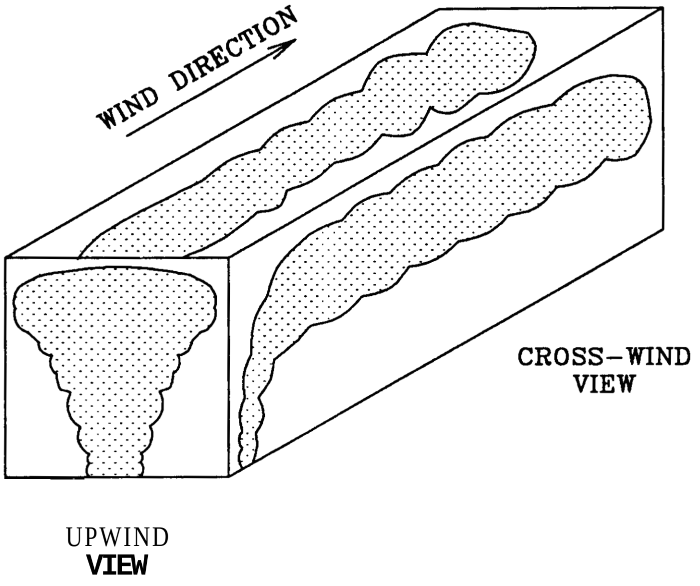
Based on detailed examination of the two available processing methods, the interactive discrete pattern recognition (IDPR) method was selected. While this approach has several limitations, the extent of its development and its adaptability to field test conditions were considered very attractive. The IDPR method was designed for use with color cameras, a PC-based MS-DOS computer system, and an image digitizer. The basic system utilizes two video camera inputs in order to capture the cross-section and the longitudinal shape of the smoke plume. The methodology is capable of accommodating additional camera positions such as overhead in the near-field and downrange beyond the near-field mixing and turbulent entrainment zone. However, these locations were not examined during the mid-scale test series. Weather conditions and scheduling necessitated concentration on two camera positions.

Several commercially available digitizing packages and related imaging software packages were evaluated. The selection of a particular package was based on evaluation of MS-DOS compatibility, speed, adaptability, and ease of use.

1.3.3 Field Measurements

As discussed above, the basic field measurements consisted of two video cameras, positioned as close to 90 degrees from one another as possible. The other principle constraint was that the cameras were to be located such that one camera was positioned upwind of the smoke plume and the other perpendicular to the smoke plume. This preferred orientation of the cameras is illustrated in Fig. 1.

3-D Image



Plan **View**

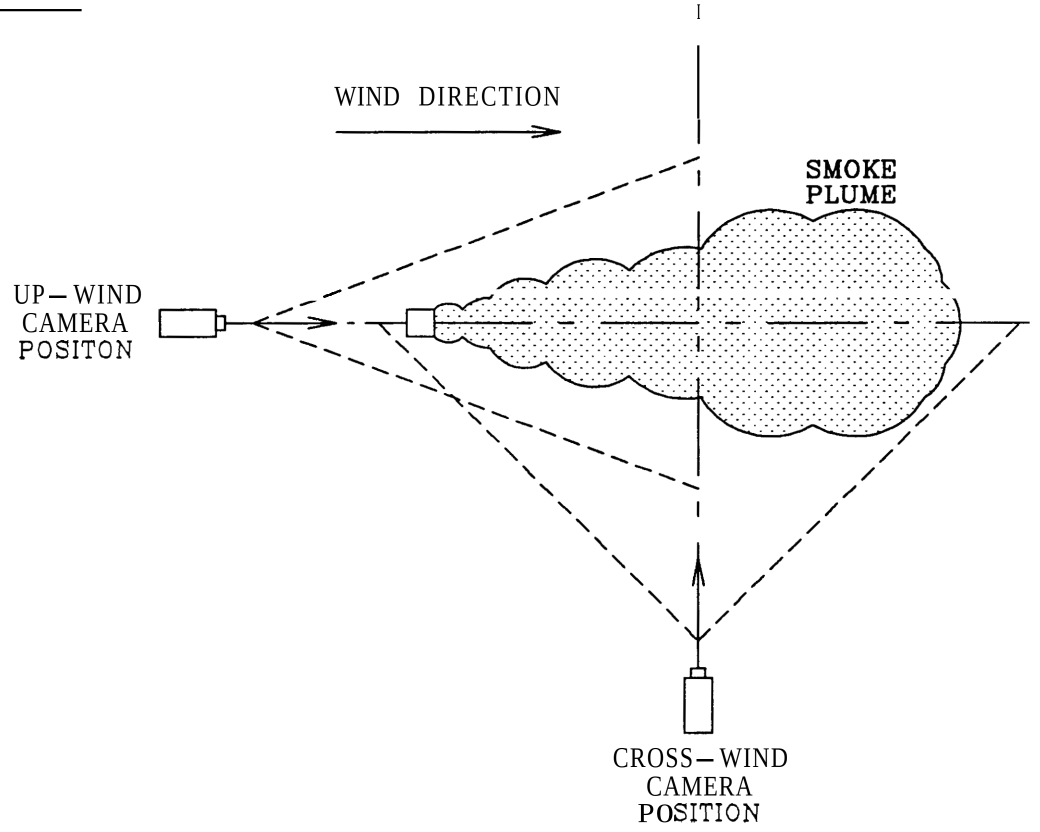


Fig. 1 - **Preferred camera positions for plume imaging in mid-scale crude oil burn tests**

The upwind or longitudinal axis camera position was used to record the width and height of the plume. The crosswind or latitudinal axis camera position was used to record the width, leading edge, and height of the plume from the other vantage point (see Fig. 2).

Frame accurate time codes were marked on each tape during the tests. Both camera views were then synchronized using the corresponding time coded frames. Time zero was set at ignition of the crude oil.

1.3.4 Data Processing

The video image data were then processed based on pattern recognition through differences in intensity, where the plume ideally rises on the back drop of a clear **sky.** The cross-sectional area of the smoke plume at a specified time and position was determined by processing the two synchronized video images. These values were then used to estimate plume volume, smoke production rate and plume trajectory at each specified time step. A computer program was developed and used to analyze and store the data in files which can later be retrieved and displayed.

The field measurement package was not designed to permit data reduction and analysis in situ. However, such a capability could be developed if deemed necessary for future applications.

1.3.5 Applicability of Existing Climatic Models

Computer models have been developed which are used to predict vapor cloud and aerosol dispersion down range from atmospheric contamination points. Typical applications of such models are focussed at examining dilution effects on gas vapor and aerosol concentrations and the ground level deposition rate of contaminants.

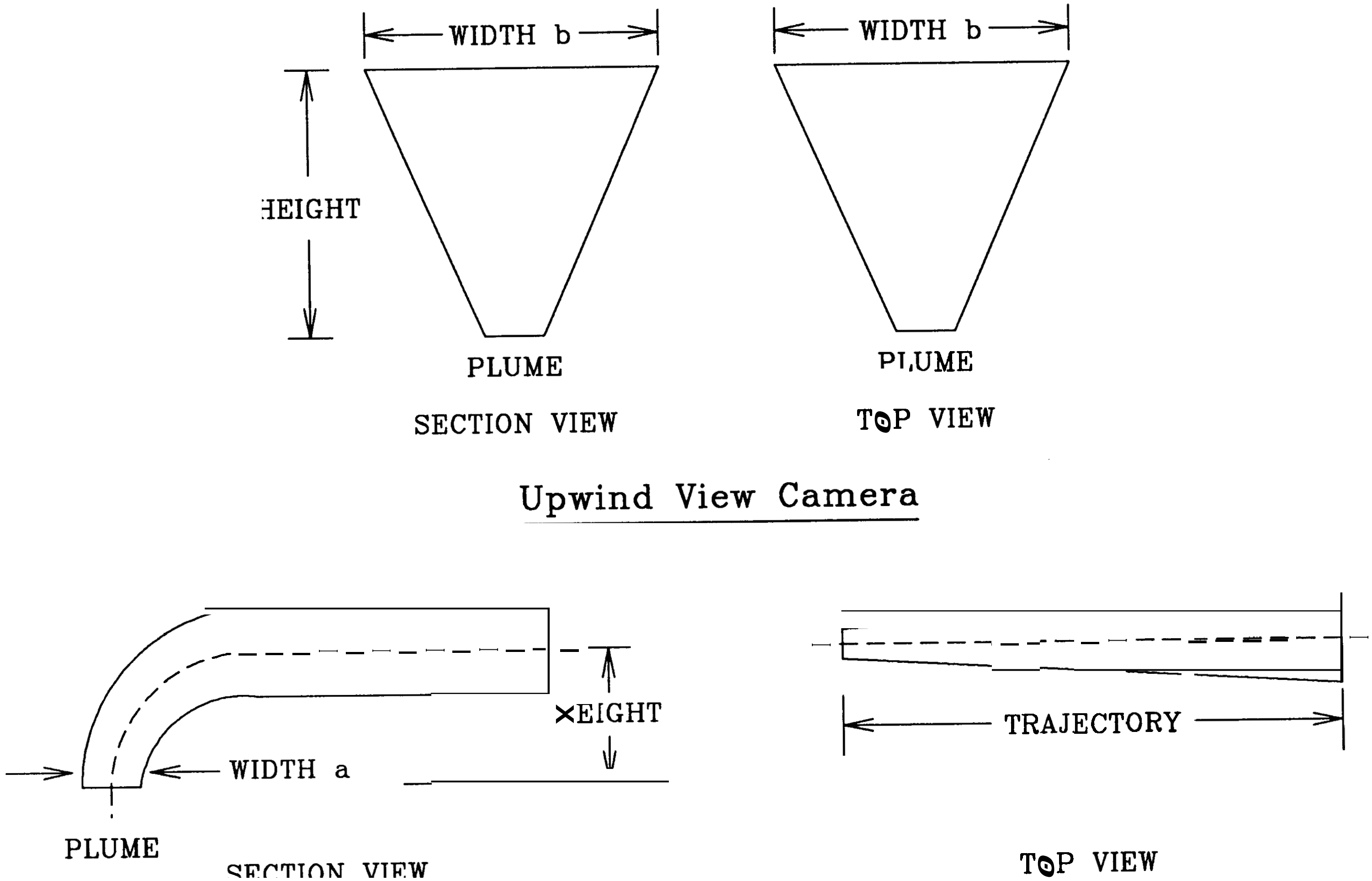


Fig. 2 - Camera views

A preliminary review was performed to identify representative climatic models and evaluate the applicability of such models to soot dispersion and deposition from burning crude oil smoke plumes.

2.0 APPLICABILITY OF AVAILABLE COMPUTER CODES

It is desirable to be able to predict the trajectory, downrange extent, and particulate deposition from a large crude oil smoke plume. By necessity, a predictive method must account for climatic and geographic effects, the burning characteristics of the fuel (crude oil), and the burning rate. The scope of this task supported a cursory review of existing computer models in order to determine their applicability.

A review of the U.S. Environmental Protection Agency (EPA) on-line bulletin board and the National Technical Information Service (NTIS) revealed a number of computer-based computational models used for prediction of large scale climatic effects. The EPA, the U.S. National Oceanographic and Atmospheric Administration (NOAA), and the U.S. Department of Energy (DOE) have developed public domain computer models for predicting global effects due to pollution, large vapor cloud releases, and climatic changes. In addition, several proprietary models are available which are similar in scope and capability to the public domain models.

Accessibility limited the evaluation to the public domain codes. The evaluation included review of selected documentation, discussions with current users of the models, and an indepth review of one representative model, INPUFF 2.0 [5].

In general, the models identified in the review are used for prediction of global or large scale effects. The effects are limited primarily to the far-field region, i.e., at locations miles downrange of an incident. These pollution or contamination models are characterized by a strong dependence on climatic/weather conditions, and output generally takes the form of mass concentrations at specified distances downrange from a release.

None of the pollution models reviewed incorporated plume buoyancy effects. Discussions with current users confirmed that near-field effects (where buoyancy directly affects the height, shape, and size of the smoke plume) are not incorporated in these models, and efforts to do so would require significant resources. At points downrange where plume buoyancy effects are lost, there is some possibility that models such as these could reasonably predict release concentrations. However, the input information necessary to run these models necessitates detailed knowledge of the downrange location and local conditions. This information is not readily available.

While a more complete investigation may identify suitable codes, the brief review of over thirty models available through the EPA bulletin board and discussions with several current users indicate that these models are not suitable for predicting near-field, fire buoyancy driven effects. A detailed review of INPUFF, a gaussian based dispersion model, supported this conclusion.

3.0 DESCRIPTION OF EQUIPMENT PACKAGE

The system consists of two Sony EVO-9100 Hi 8 mm color video cameras for data collection; one Sony EVO-9500 Hi 8 mm video playback unit for data viewing and retrieval; a Truevision VidI/O video conversion box to convert S-Video output of playback unit to RGB 15 kHz for input to the video digitizer; and one Sony Trinitron color monitor used for both tape preview and for digital video interpretation. The digital equipment consists of a custom designed 20 mHz Intel 80386 based MS-DOS compatible computer with a VGA board and monitor and a Data Translations 2871-HSI Video Digitizing card for data capture and processing (see Appendix A for a complete list of equipment).

4.0 INFORMATION PROCESSING

4.1 Algorithm

The first step in analyzing the videotapes recorded during the fire tests involved digitizing and manipulating single frames of video. Initially, a scaling factor was determined from a known object height (e.g., reference point), which provided a reference scale in meters per pixel. This was done for both the upwind camera view and the crosswind camera view. Due to CPU time constraints, the plume was digitized every fourth pixel. This sped up the editing process and calculation times considerably.

Once the frame is digitized, the computer program analyzes the image and determines which areas represent the smoke plume. This is accomplished by contrasting the image intensity between the smoke and the surrounding atmosphere. This step is performed automatically by the computer program.

If the program overestimates the plume size by including clouds and other background interference or if it underestimates the plume size, then the user can increase or decrease the intensity to edit and modify the plume. Once the user is satisfied with the shape of the plume, the program stores the data to a bit map. This is done for both views.

The final step involves the determination of volume, production rate, and trajectory. The program performs several geometric calculations, using two different approaches, to provide estimates of smoke volume, smoke production rate, and plume trajectory. One approach incorporates video images from two camera locations; the alternative method incorporates a single-camera image.

4.2 Input

The input routine is menu driven and prompts the user for each input element. The user is required to input the camera(s) compass headings, distances from the base of the fire to the cameras, and the wind direction also in terms of a compass heading execution. These data, along with other descriptive information, are stored in **a** data file prior to execution of the program.

4.3 Calculations

4.3.1 Two-camera Method

Ideally, in the two-camera approach, the video cameras are positioned at ninety-degree angles to one another as illustrated in Figure 1; one camera upwind from the plume and the other camera positioned crosswind (e.g., perpendicular) to the plume. The direction of the smoke plume is assumed to be the same as the direction of the wind. From each of these two views, the number of horizontal pixels across the smoke plume **is** determined from the digitized frame. These values are multiplied by the scaling factor to calculate the widths of the plume from the two camera views, where "a" is equal to the width of the plume from the crosswind camera location and "b" is the width determined from the upwind camera location (reference Figure 2). The widths of the plume are measured at preselected height increments of ten meters.

In anticipation that configuring the cameras exactly as depicted in Fig. I may not be possible under field conditions, the program was modified to correct the images for other than parallel or right angle orientations. In the event that the cameras cannot be positioned parallel (upwind) and perpendicular (crosswind) to the smoke plume, the plume width and length are corrected using simple geometric relationships (see Figs. 3 and 4).

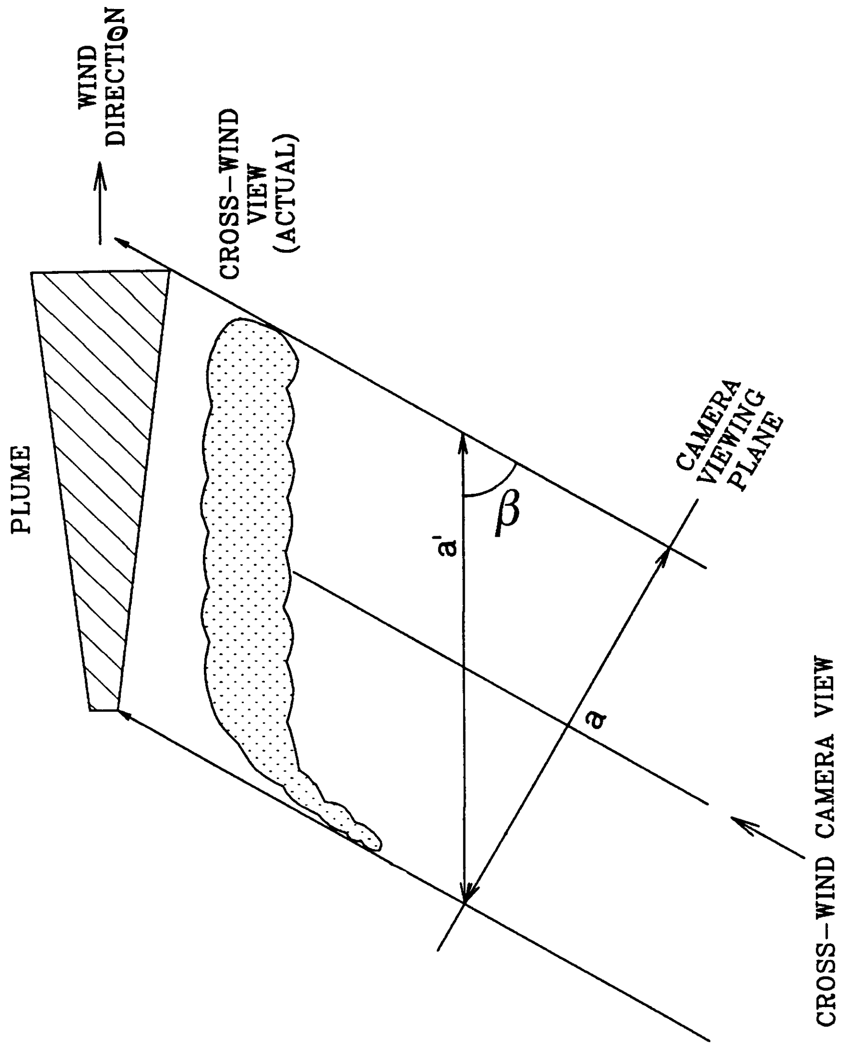


Fig. **3 - Geometric correction to estimated plume length**

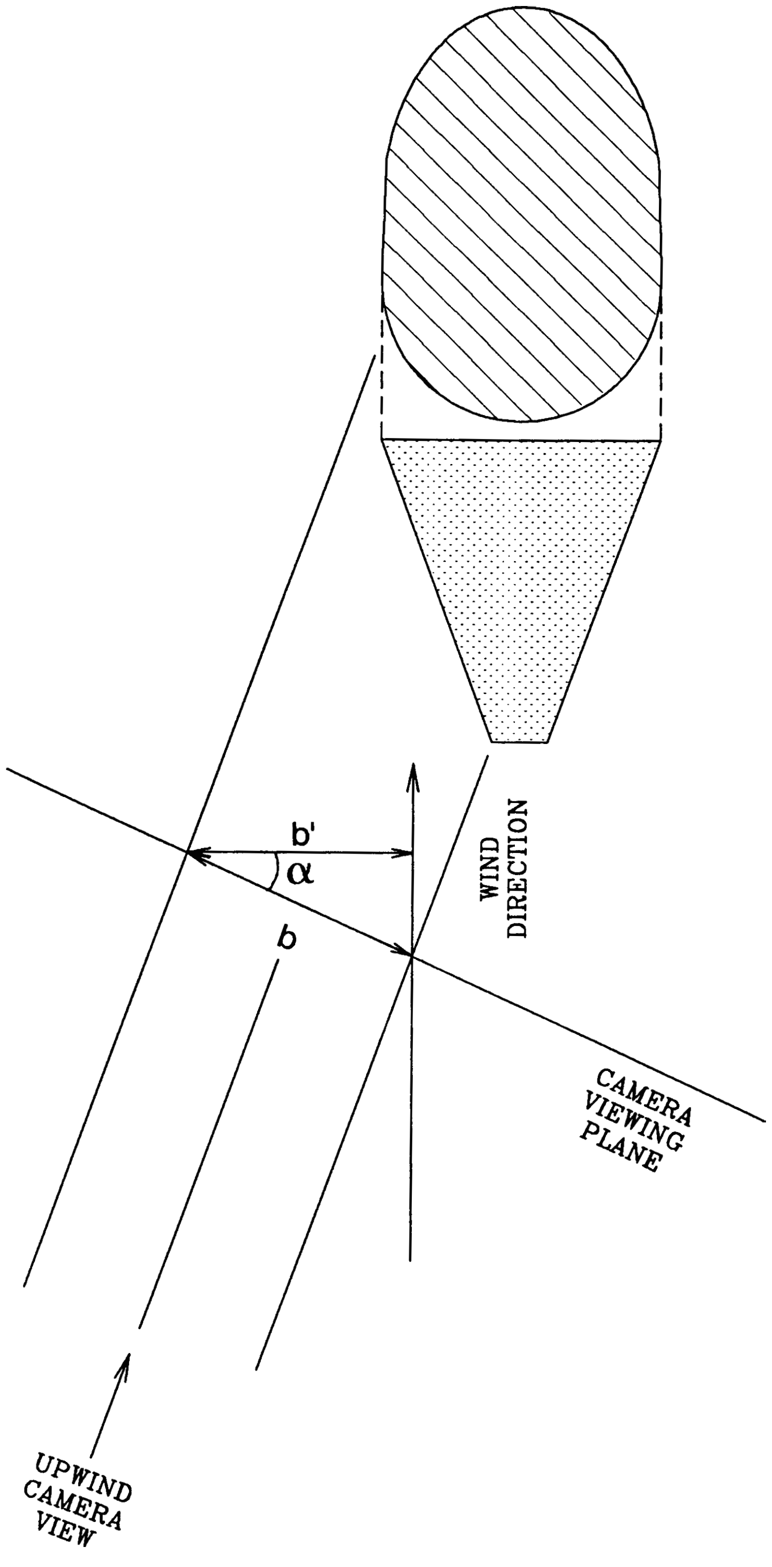


Fig. 4 - Geometric correction to estimated plume width

The corrected perpendicular or crosswind plume width (a') is determined using the equation:

$$a' = \frac{a}{\sin \beta} \tag{1}$$

where a' = corrected smoke plume width (m);

a = smoke plume width as viewed through the video camera (m); and

β = angle between the crosswind camera view and the smoke plume latitudinal axis.

This correction produces an image more closely representative of a view perpendicular to the smoke plume.

The upwind camera view width (b') is calculated in the same manner. The upwind plume width is determined using the following equation:

$$b' = b\,(\cos \alpha) \tag{2}$$

where b' = corrected smoke plume width (m);

b = smoke plume with as viewed through the video camera (m); and

α = angle between the upwind camera view and the smoke plume longitudinal axis.

The corrected widths (a' and b') are then substituted into equations (3), (4), and (5) to calculate the area, volume, and smoke production rate of the plume. Once the extent of the smoke plume is beyond the viewing angle of the camera, the computer program uses the last calculated width "a" or "b" in succeeding calculations.

The cross-sectional areas of the plume are calculated as elliptical sections at each height increment using the following equation for the area of an ellipse:

$$A = \frac{\pi \, a \, b}{4} \tag{3}$$

where A = cross-section area of the smoke plume (m^2);
a = plume width from the crosswind camera view (perpendicular to the plume) (m); and
b = plume width from the upwind camera view (m).

The volume of the smoke estimated based on the sum of the cross-sectional areas of the plume multiplied by a set height increment of ten meters. The following equation is used to calculate the volume:

$$V = 10 \left(\sum_{i=1}^{n} A_i \right) \tag{4}$$

where n = number of height increments.

The volume calculation is performed for each frame digitized over a set time step. The smoke production rate is then estimated by calculating the difference in the smoke volume between two sequential frames divided by the time step. The following equation is used to calculate the production rate:

$$\dot{V}_n = \frac{(V_n - V_{n-1})}{\Delta t} \tag{5}$$

where $\dot{V}$ = volumetric smoke production rate (m^3/min);
V_n = volume of smoke from frame n (m^3);
V_{n-1} = volume of smoke from frame n-1 (m^3); and
Δt = time between frames (min).

As the areas and corresponding volumes are determined for each height increment, the sum of the vertical pixels is also recorded by the program. The height of the smoke plume is then calculated by multiplying the scale factor by the sum of the vertical pixels in the plume.

4.3.2 Sinale-camera Method

The computer program was modified to perform the necessary calculations based on images from a single camera. For the one-camera approach, **a** centerline trajectory method is used to perform the calculations. These calculations are performed based on video images from the view perpendicular to the direction of the plume (crosswind view). After the program has retrieved a previously digitized image, the user is prompted to overlay a centerline on the smoke plume. An equation is determined for the line segment between each point set by the user. The radius of the plume, which is defined as the distance between the centerline and the edge of the plume perpendicular to the centerline, is then determined at seven locations (equidistant along the centerline) (see Fig. 5). The highest and lowest values are deleted, and the remaining five are averaged to produce an average radius for that segment of the plume. Deleting the high and low values reduces the problem of inconsistencies in the plume which could skew the overall results. The volume of each segment of the plume is determined using a solid cylinder approximation. The equation used to calculate the volume of each segment is the following:

$$V_s = \pi R_s^2 L, \tag{6}$$

where **s** = corresponds to the line segment number;
V, = volume of cylinder (m^3);
R, = average radius of the cylinder (m); and
L_s = length of the cylinder/line segment (m).

The volumes of each segment are then added together over the entire length of the plume to produce the total volume.

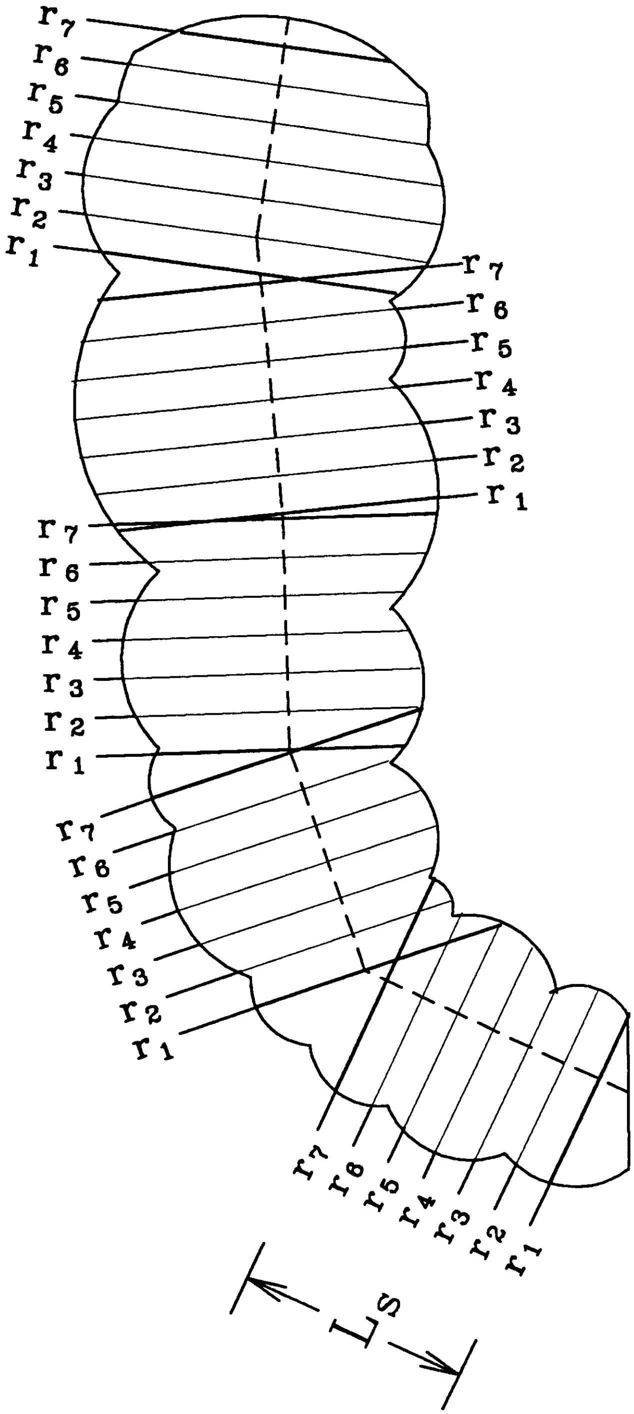


Fig. 5 - Plume centerline estimation

The centerline method is also used to determine the trajectory of the smoke plume. Starting from the base of the fire as the origin, the x and y values along the line segments making-up the centerline of the plume are recorded over the entire length of the plume (see Fig. 6). These values are then used to represent the trajectory of the plume. The maximum y value corresponds to the maximum centerline height of the plume. Again, the direction of the smoke plume is assumed to be the same as the wind direction.

4.4 output

Program output includes a summary table, graphical displays for each time step, and centerline trajectory coordinates. An example of the summary table is illustrated in Table 1 and contains required input data and camera location information. Figure 7 illustrates typical graphical output which includes the digital image of the plume for both camera locations and calculated values for plume height, distance, volume, and smoke production rate. Calculated values are provided for both the single and two-camera approach. Table 2 illustrates the output form for plume trajectory coordinates. It should be remembered that the plume trajectory calculations are based on the images from the crosswind camera location only.

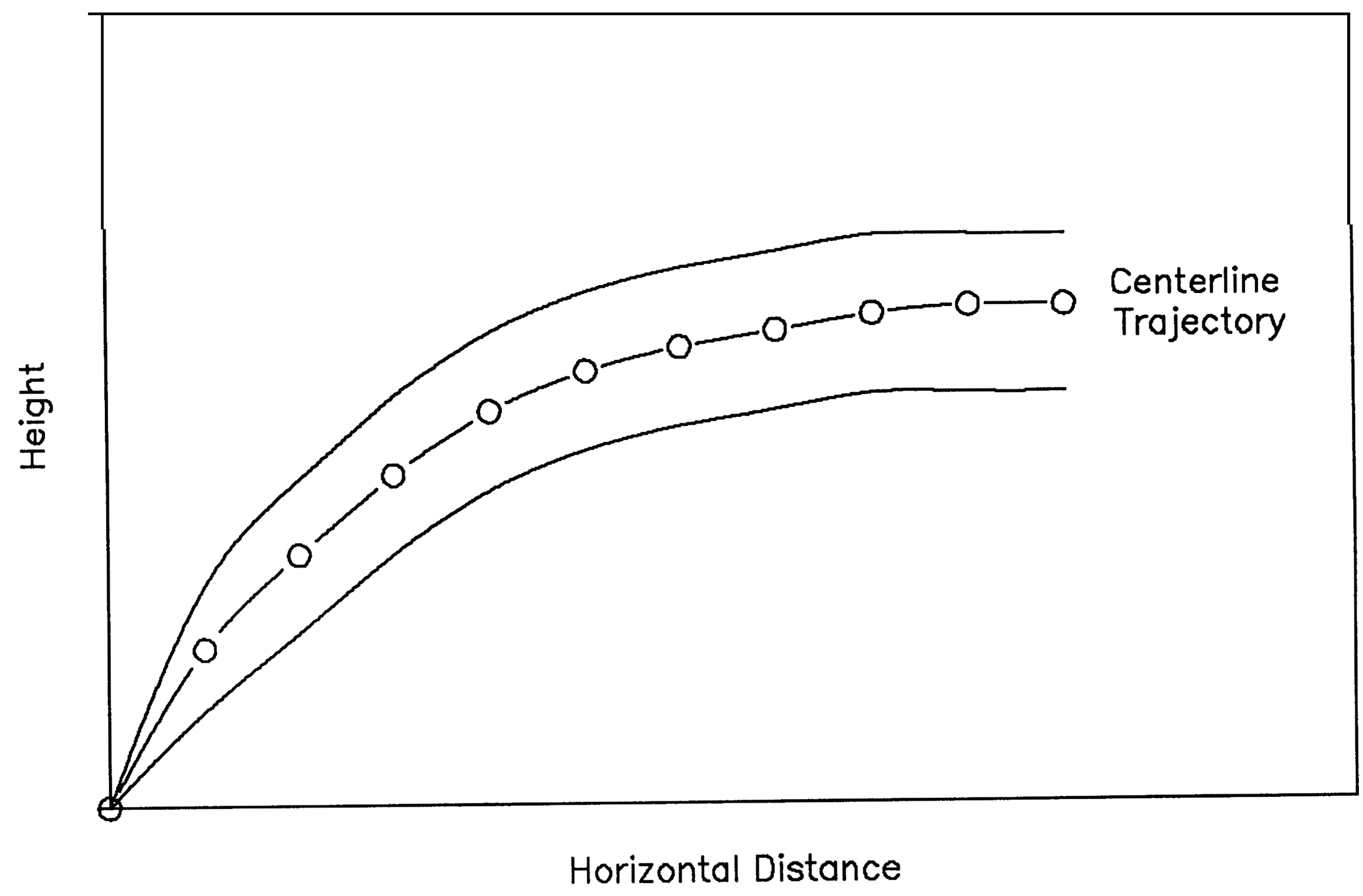


Fig. 6 - Plume centerline trajectory

Table 1. Typical Field Test Input Data (Test 1)

Test No: 1
Date of Test: 4/16/91
Time of Test: 10:00

Test Description: 20 ft by 20 ft pool fire

Wind Speed: 1.3 m/sec
Wind Direction: 170 degrees

Front View Camera Direction: 90 degrees
Front View Camera Distance: 120 m
Side View Camera Direction: 0 degrees
Side View Camera Distance: 120 m

Test Length: 60 seconds
Time Step: 30 seconds

Table 2. Tabulated Smoke Plume Distance and Height Trajectory Output at 30 s Elapsed Time (Test 1)

Plume Trajectory

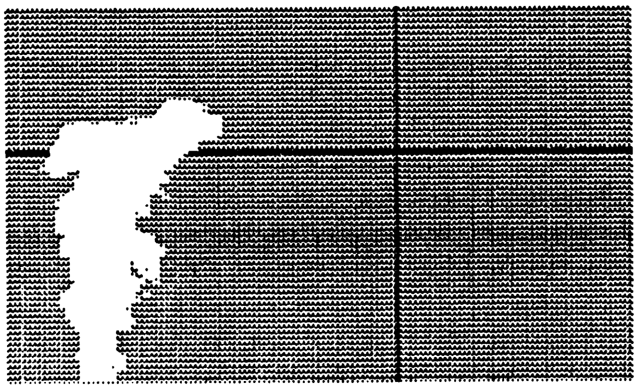
Test 1
Compass Heading 350°
Elapsed Time = 0:30 (m:s)

Distance (m)	Height (m)
0	0
0.209612	6.670783
0.4192271	13.3498
0.6288431	20.03703
0.838459	26.7325
1.04807	33.43619
1.257686	40.14809
2.096145	47.79309
2.934599	55.47512
3.773059	63.19416
4.611518	70.95023
5.449972	78.74332
6.288431	86.57344
6.288431	86.57344
7.12689	91.88812
7.965344	97.22748
8.803802	102.22748
9.642261	107.9803
10.48072	113.3937
11.31918	118.8318

TEST NUMBER : 1
ELAPSED TIME : 00:30

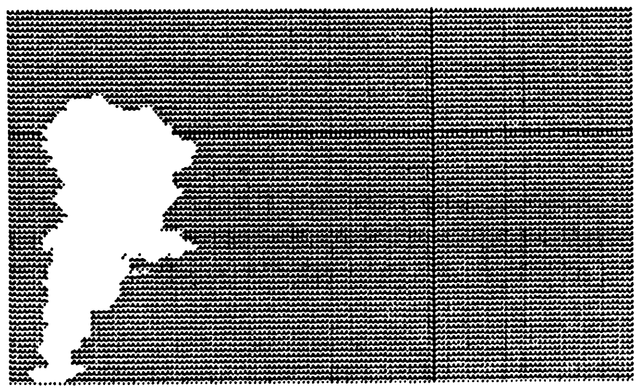
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	120	118	METERS
MAX. DISTANCE :	41	11	METERS
VOLUME OF SMOKE :	42915	44082	CU. METERS
PRODUCTION RATE :	85831	88165	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

Fig. 7 - Example digitized smoke plume image and calculated values (Test 1)

5.0 FIELD TESTS

5.1 Objectives/General Description

Mid-scale field tests were conducted at the U.S. Coast Guard facility in Mobile, Alabama [6]. These tests were used to determine the optimal approach for viewing and analyzing the smoke plume from a range of different camera setups. The first series was a set of scoping tests which were conducted by NIST in April 1991. This test series was used to test the measurement equipment in the field, to select initial video camera positions for viewing the smoke plume, to obtain baseline data for the software algorithm, and to prepare and develop a preliminary procedure to be used in the field tests scheduled for May 1991. This second series of tests was used to implement the procedure developed during the initial testing, to evaluate the algorithm developed for computing the smoke plume volume, production rate, and trajectory, and to further examine different camera locations.

A key factor affecting video recording of the smoke plume for these tests was the weather. The visibility needed to be clear with no rain. This requirement was necessary in order to track the plume and provide a clear video image that could be distinguished from background. The positions of the cameras for each test were determined by the wind direction.

The wind direction and speed were the most difficult weather conditions to predict and account for in deploying the video cameras. Due to limitations in site availability, it was difficult to attain a ninety degree position between the two cameras when the wind suddenly shifted direction.

When the wind speed was low, less than 3 m/s (5 mph), the smoke plume traveled nearly straight up. At wind speeds less than 2 m/s, the plume was characterized by inverted shapes and pockets of entrained air mixed with the visible smoke. Such effects could introduce considerable error into the calculations. At wind speeds greater than around ***6* m/s,** the plume was rapidly diluted, resulting in difficulty in using the discrete pattern recognition method to separate the edges of the plume from the background.

5.2 General Equipment Locations/Orientation

The optimum location for the two cameras to document the smoke plume was unclear before the test series began. To find the preferred positions, the camera setups were varied for each of the tests. These locations are shown in Figure 8. Shifting weather patterns and limited site availability complicated location of the camera positions. As a result of this and the magnitude of the test fires, it became clear during the test series that the cameras should be located as far away from the fire source as possible. The loss in accuracy is necessary if the position and extent of the visible smoke plume are to be estimated beyond one to two minutes.

5.3 Procedure

The series of mid-scale tests conducted were designed to simulate the burning of crude oil on sea water for the purpose of examining instrumentation methods and providing data. Video taping of the smoke plume provided data for the development of software to calculate plume volume and determine its position.

Based on the weather forecast for the next day, the Mobile Flight Service Station and the Coast Guard ATC were notified that a test is likely. On the day of the test, if weather conditions appeared favorable, the test crew moved to Little Sand Island, and the airborne weather instrumentation was setup to determine the local weather conditions. Subsequently, a decision was made by the test director and safety officer to start the test sequence. The time between the start of the test sequence and ignition was set at one hour. A detailed description of the test procedure can be found in reference [7].

Once the wind speed and direction were known, the video equipment was deployed. Preferably, one camera was placed upwind of the plume and the other camera

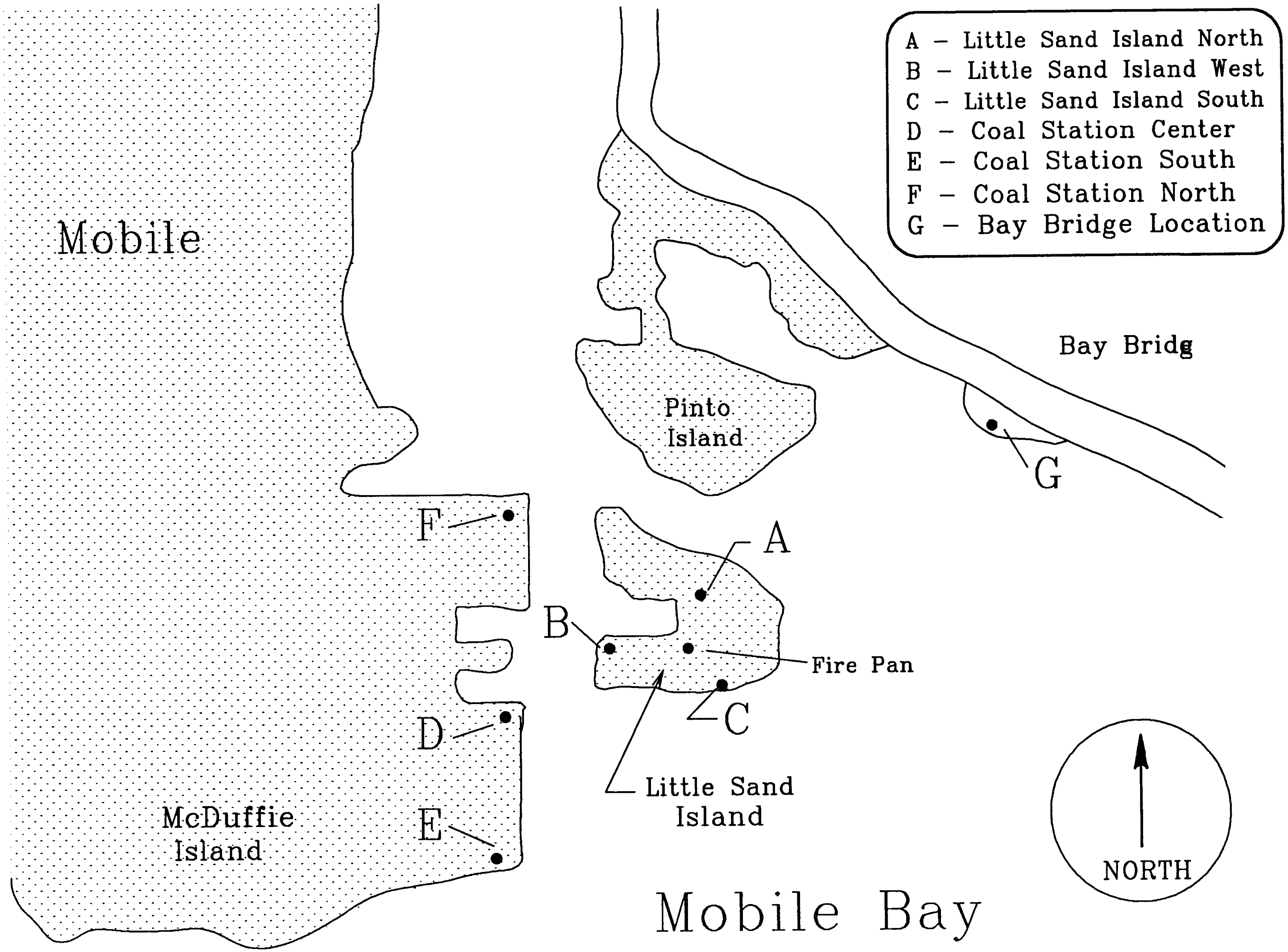


Fig. 8 - Mid-scale field test camera locations

perpendicular to the plume. Once the cameras were setup, the compass headings were determined and recorded for the camera positions, and the angle above the horizontal was measured. The estimated distance to the fire pan was also recorded for both cameras. When the pan was ready for fueling all personnel were informed. Video taping commenced at this point so that the ignition of the crude oil would be documented on the videotape. The ignition of the oil was used to synchronize the two cameras. The cameras remained stationary during the entire test sequence. When the fire was out or when the plume was out of the video screen, video recording was terminated.

5.4 Individual Test Configurations/Setup

As documented in Table 3, it was difficult to locate the cameras in order to replicate the preferred test configuration illustrated in Fig. 1. As previously described, this configuration included one camera positioned upwind of the smoke plume providing a viewing angle parallel to and centered on the downrange longitudinal axis. It also included a second camera positioned perpendicular to the downrange longitudinal axis. Ideally, this would result in a 90 degree angle between the two cameras. As already discussed, changes in wind direction and limitations in site location limited the ability to achieve the preferred configuration. This resulted in the need to provide for adjustments or corrections in the digitized images, a capability that was incorporated in the computer program (see Section 4.3). As can be seen from the test information in Table 3, corrections were required for all eight tests.

For Test 1, both cameras were located relatively close to the fire. Camera 1 was positioned perpendicular to the plume at a compass heading of 90 degrees and camera 2 was located down wind from the plume at 180 degrees. The wind direction was 350 degrees at a speed of 1.3 m/s (3.25 mph). After about 30 seconds into the test, the smoke plume was at a height beyond the field of view for both camera 1 and camera 2.

In order to track the plume and maintain it within the video screen's range for a longer period, camera 1 was positioned across the bay on McDuffie Island next to the

Table 3. Field Test Summary

Test	Date	Wind Speed m/s mph	* Wind Direction (deg.)	Camera 1 Location	Distance to Fire Pan m (ft)	* Camera 1 Direction (deg)	Angle Between Camera 1 & the Plume (deg)	Camera 2 Location	Distance to Fire Pan m (ft)	* Camera 2 Direction (deg)	Angle Between Camera 2 & the Plume (deg)	Angle Between Camera 1 & Camera 2 (deg)	Pan Size m x m (ft x ft)	Fuel Amount Gal. (l)
1	4/16/91	1.3 (3.25)	350	B	125 (410)	90	80	A	125 (410)	180	10	90	6.1 x 6.1 (20 x 20)	1893 (500)
2	4/17/91	1-3 (2.5-7.5)	268	D	650 (2133)	75	33	C	125 (410)	330	42	105	6.1 x 6.1 (20 x 20)	1893 (500)
3	5/16/91	3.3 (8.3)	340	D	650 (2133)	90	70	E	900 (2953)	30	50	60	6.1 x 6.1 (20 x 20)	3407 (900)
4	5/17/91	2.7 (6.8)	320	D	650 (2133)	75	65	E	900 (2953)	35	75	40	6.1 x 6.1 (20 x 20)	3785 (1000)
5	5/28/91	3.0 (7.5)	350	F	900 (2953)	145	25	D	650 (2133)	50	60	95	10.7 x 10.7 (35 x 35)	4042 (1068)
6	5/29/91	10.0 (25)	20		900 (2953)	145	55	D	650 (2133)	42	22	103	10.7 x 10.7 (35 x 35)	3816 (1008)
7	5/30/91	3.0 (7.5)	350	G	3500 (11,480)	250	80	D	650 (2133)	42	52	28	10.7 x 10.7 (35 x 35)	6563 (1734)
8	5/31/91	1.5 (3.8)	290	G	3500 (11,480)	240	50	D	650 (2133)	42	68	18	15.2 x 15.2 (50 x 50)	10,598 (2800)

* = Compass heading
A = Little Sand Island North
B = Little Sand Island West
C = Little Sand Island South
D = Coal Station Center
E = Coal Station South
F = Coal Station North
G = Bay Bridge Location

coal station for Test 2 (see Figure 8). The compass heading for camera 1 was 75 degrees; camera 2 was positioned at 330 degrees on Little Sand Island. The wind direction and speed were 288 degrees and 1-3 m/s (2.5-7.4 mph) respectively. Just prior to initiation of Test 2, the wind direction shifted. Due to the lack of site availability, camera 2 could only be moved along the coal station on such short notice. As a result, camera 1 and camera 2 were not 90 degrees apart, nor were they perpendicular and parallel to the smoke plume. The image of the smoke plume extended beyond the camera range for camera 2 after 90 seconds. However, the increased distance to camera 1 provided a satisfactory viewing angle for up to four minutes for this test.

The second series of mid-scale field tests began during the second week in May 1991. For Test 3, the video cameras were both positioned on McDuffie Island to obtain the best view possible, given the varying weather conditions. Camera 1 was placed at the center of the coal station with a compass heading of ninety degrees, while camera 2 was positioned on the south end of the coal station at a compass heading of 30 degrees (see Figure 8). The wind was 3.3 m/s (8.3 mph) at a compass direction of 340 degrees. This wind speed was strong enough to bend the plume over. The fire was a 6.1 x 6.1 m (20 x 20 ft) pan with 900 gallons of crude oil, which allowed a burn time of approximately 20 minutes. Camera 2 provided a view of the plume initially traveling towards the north. Then, as the plume traveled over the water, it changed to a southerly direction down Mobile Bay. After approximately two minutes, the plume image was extended beyond the viewing angle for camera 1. However, the image was maintained within the viewing angle for camera 2 for the remainder of Test 3.

In Test 4, camera 1 was located at the center of the coal station and camera 2 was located at the south end of the coal station. Camera 1 was at a compass heading of 75 degrees and camera 2 was at 35 degrees. The wind was at a speed of 2.7 m/s (6.8 mph) with a compass heading of 320 degrees. Again, due to the shifting wind, it was difficult to get the necessary ninety degree angle between the two cameras and the appropriate upwind and perpendicular views of the smoke plume. Test 4 used a 6.1 x 6.1 m (20 x 20 ft) pan fire with 1000 gallons of crude oil. The wind speed was sufficient to create a conventional bent-plume shape, but after 4 minutes into the test, the visible plume was out of the viewing range for both cameras. After reviewing videotapes of these tests, it was decided that the camera locations would be changed again to account for the large smoke plume.

For Test 5, camera 1 was positioned on the northern tip of the coal station island and camera 2 was located at the center of the coal station (see Figure 8). Camera 1 had a direction of 145 degrees and camera 2 was positioned at a compass heading of 50 degrees, which gave a 95 degree angle between the two cameras. The wind speed was 3 m/s (7.5 mph) with a compass heading of 350 degrees. This gave an almost downwind view of the plume for camera 1 and an angle of 60 degrees to the smoke plume for camera 2. The fire was a 10.7 x 10.7 m (35 x 35 ft) pan fire with 4042 L (1068 gal) of crude oil. In the camera 1 view, the plume rose out of the viewing range after two minutes; for camera 2, the leading edge of the plume was lost after 2.5 minutes.

In Test 6, camera 1 was located at the north end of the coal station at a compass heading of 145 degrees and camera 2 at the center of the coal station with a direction of 42 degrees. A 103 degree angle was formed between the two cameras. The wind speed was 10 m/s (25 mph) at a compass direction of 20 degrees. As a result, camera 2 had an almost upwind view of the smoke plume. Camera 1 was positioned 55 degrees to the plume. A 10.7 x 10.7 m (35 x 35 ft) pan fire was used with 3815 L (1008 gal) of crude oil burned. Since the wind was gusting very high, the plume immediately began to bend and the smoke moved rapidly across the bay. After 2 minutes and 45 seconds, the leading edge of the plume was beyond the field of view of camera 2. The time to extension of the plume beyond the viewing angle for camera 1 was even shorter at only 2 minutes.

Beginning with Test 7, camera 1 was located at the Bay Bridge with a compass heading of 250 degrees. This was done in order to maintain the plume inside the viewing field of the camera for a longer period of time. Camera 2 was again placed at the center of the coal station with a direction of 42 degrees. The two cameras were looking almost directly across from one another. The wind speed at test time was 3.0 m/s (7.5 mph) with a direction of 350 degrees. For camera 1, there was an almost perpendicular view to the smoke plume while camera 2 had a 52 degree angle with the plume. The size of the fire was a 10.7 x 10.7 m (35 x 35 ft) pan with 6562 L (1734 gal) of crude oil, which gave a burn time of approximately 20 minutes. The wind was strong enough to bend the plume and after only 1 minute and 30 seconds the plume was off the screen for camera 2. The significant increase in distance to camera 1 resulted in video imaging of the entire plume for a longer period during the test.

Test 8 was the largest fire of the large scale field test series. The pan was 15.2 x 15.2 m (50 x 50 ft) with 10,598 L (2800 gal) of crude oil, which gave a burn time of approximately 18 minutes. The wind speed was 1.5 m/s (3.8 mph), resulting in no noticeable bending over of the smoke plume. The wind direction was 290 degrees. Camera 1 was located near the Bay Bridge with a compass heading of 240 degrees, and camera 2 was positioned at the center of the coal station at 42 degrees. Again, the two cameras were essentially facing one another. After 11 minutes into Test 8, the smoke plume was out of the viewing range of camera 1; camera 2 lost the plume in less than 1 minute.

6.0 FIELD TEST RESULTS

The video images obtained in each of the eight mid-scale crude oil tests were reduced and analyzed. The analysis included frame digitizing of the visible smoke plume and subsequent calculation of the plume height, downrange distance, volume, volumetric production rate, and centerline position. When appropriate, calculations were based on both the single and two-camera methods.

Typical output from the imaging process is illustrated in Fig. 9. The series of images were computed from the output from the crosswind camera position in Test 7 to demonstrate the sequential change in height and downrange extent of the visible smoke

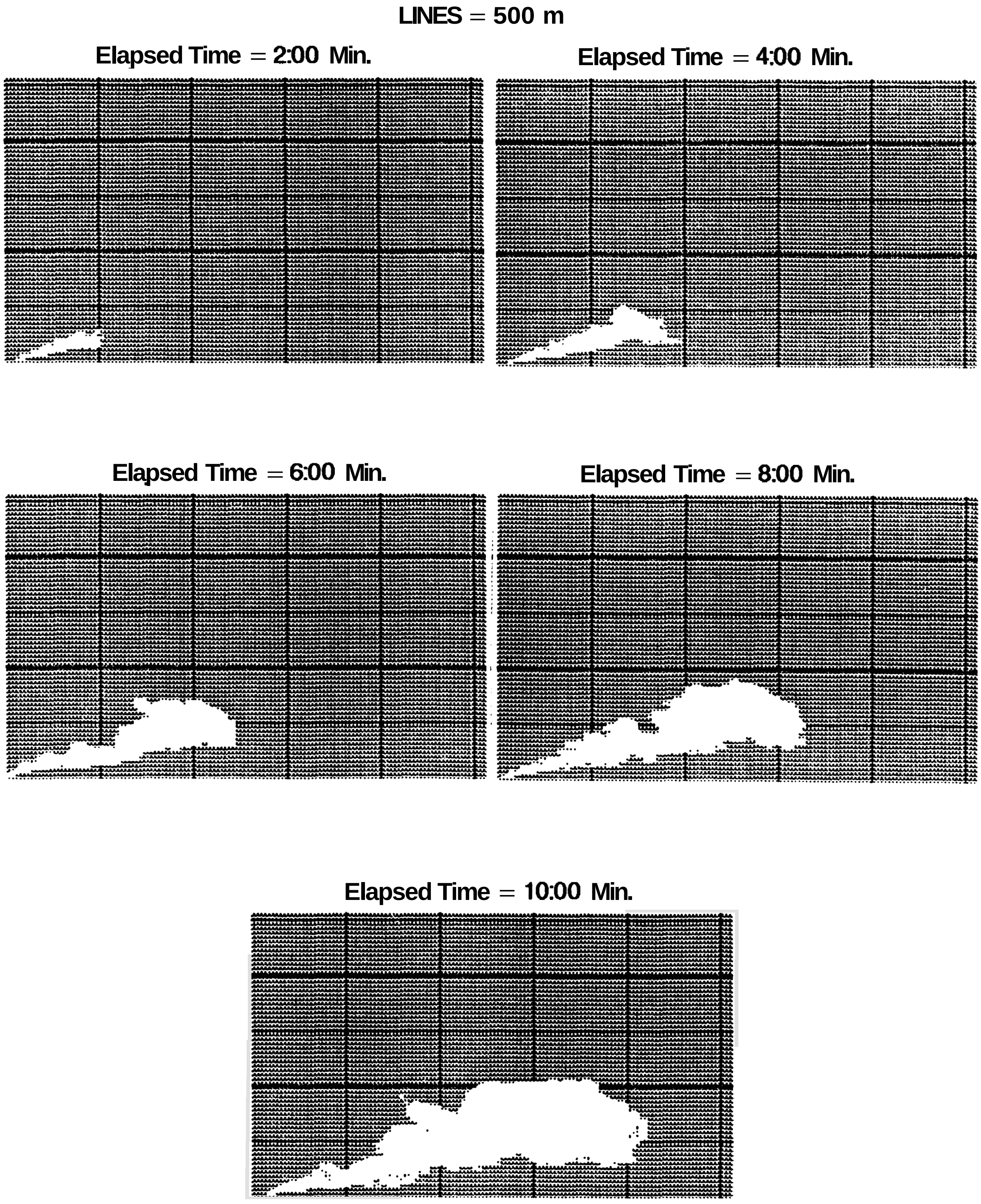


Fig. 9 - Typical image output from crosswind camera position (Test 7)

over several time steps. The wind speed associated with this test was measured at 3 m/s (7.5 mph).

Table 4 provides a summary of the plume height, downrange distance, volume, and volumetric production rate for both the single and two-camera calculation procedures. Coordinates associated with the downrange leading edge of the plume are based exclusively on output from the centerline trajectory estimates from the single-camera (i.e., crosswind position) method. A graphical representation of the leading edge position of the plume at each time step is presented in Fig. 10 for Test 7. The calculated values indicate that neutral buoyancy was approached at around 10 minutes after ignition. This could not be confirmed based on additional downrange images because the plume extended beyond the field of view for the crosswind camera position at a horizontal extent of 2000 m (6560 ft).

Calculations and graphical output are summarized in Appendix B for the eight mid-scale tests in which video imaging was attempted. It should be recognized that camera locations, wind direction, and fire size varied among tests. The results are an attempt to demonstrate the efficacy of such measurements and calculations, and are not intended for comparative analysis of the fire or plume characteristics among individual tests.

7.0 DISCUSSION

7.1 General

The methodology developed during the mid-scale crude oil fire tests for smoke plume imaging appears promising. The discrete pattern recognition technique provided reasonable discrimination between visible smoke and background, generally preserving the plume shape and extent. The inclusion of an interactive module in the program further enhanced the discrimination capability by permitting the user to adjust the gray scales or actually modify the boundary location superimposed on the video image prior to image digitizing.

Table 4. Summary of Smoke Plume Calculations (Test 7)

Elapsed Time (min)	Single-camera Method				Two-camera Method			
	Height (m)	Distance (m)	Volume ($m^3 \times 10^6$)	Rate ($m^3/min \times 10^6$)	Height (m)	Distance (m)	Volume ($m^3 \times 10^6$)	Rate ($m^3/min \times 10^6$)
2:00	158	432	1.75	0.88	300	300	1.6	0.80
4:00	375	727	10.42	4.33	580	540	9.91	4.16
6:00	476	1126	57.73	23.66	800	680	32.42	11.26
8:00	658	1348	134.0	67.0	980	1140	65.9	32.97
10:00	782	1824	380.94	190.47	1200	1400	143.84	71.92

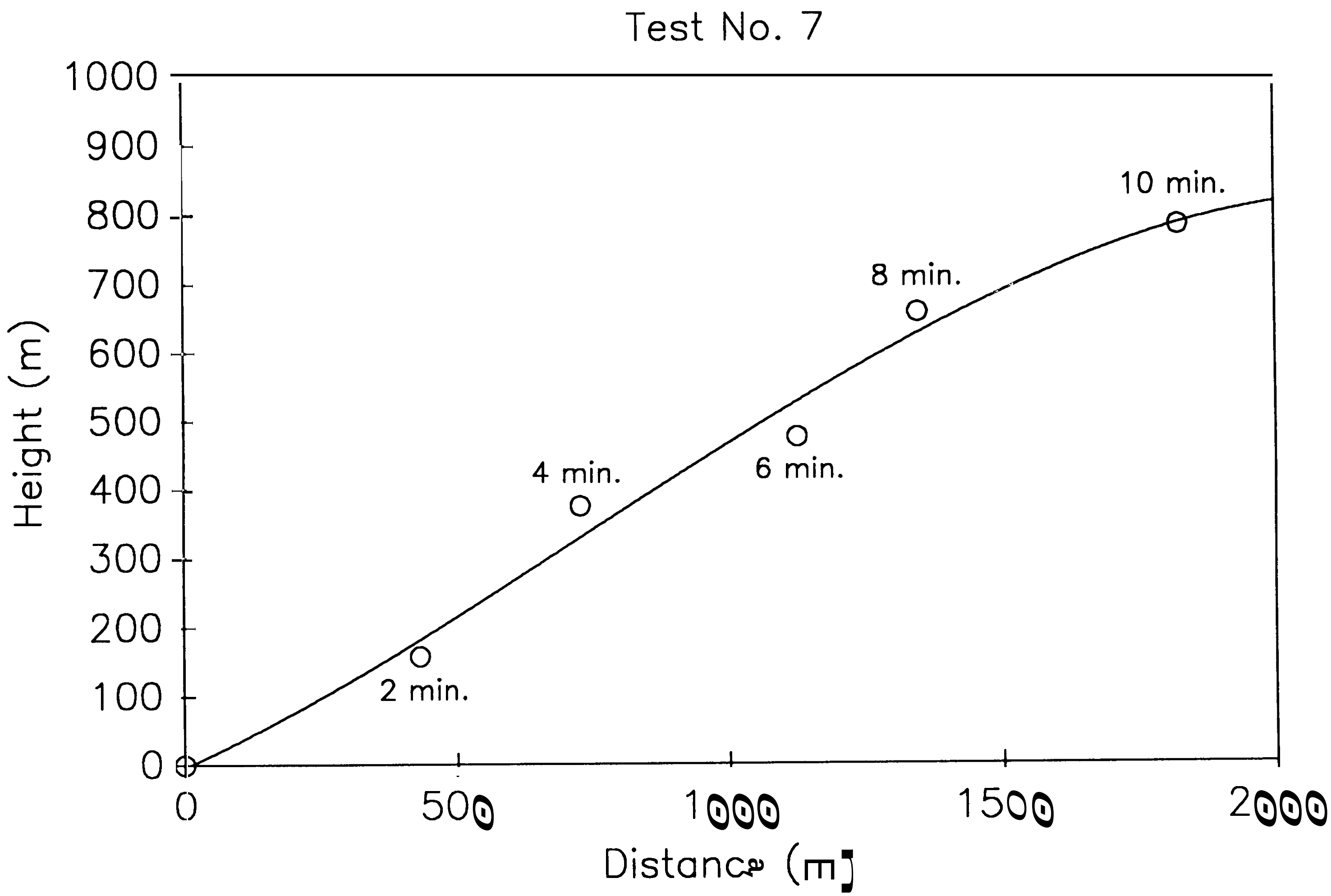


Fig. 10 - Visible smoke plume leading edge position at selected time increments (Test 7)

The computer program is menu driven and relatively simple to use. It is MS-DOS compatible and will produce estimates of plume height, extent, volume, and smoke production rate for either the single-camera or two-camera method. Both methods employ calculations based on the assumptions that the smoke plumes are elliptical in cross-section and relatively uniform along the perimeter boundaries. The error introduced can be reduced to some degree through selection of smaller incremental sections. However, several other sources of error exist, including the selected scale factor, localized temperature and wind, and camera viewing angle relative to the smoke plume geometry.

While difficult to anticipate prior to the field testing, review of the video images indicated that in general, cameras must be located at significant distances from the fire source in order to capture the full extent of the plume over several minutes. The graphical images provided in Appendix B demonstrate the loss of the smoke plume from the field of view of the cameras very quickly when the cameras were positioned within 1000 m of the fire source. Frequently, this occurred in less than one minute after ignition, significantly limiting estimates of smoke plume shape and downrange extent.

Evaluation of various camera locations and vantage points confirmed that the camera distance to the base of the plume corresponds approximately to the downrange view of the available camera lens (e.g., 1:1 ratio). This would be expected for the type of lens used. Therefore, if one is interested in monitoring the plume for a distance of one mile downrange, the crosswind camera must be located approximately one mile away from the base of the fire and perpendicular to the prevailing wind direction. The results from Test 7 (Appendix B) demonstrate this effect.

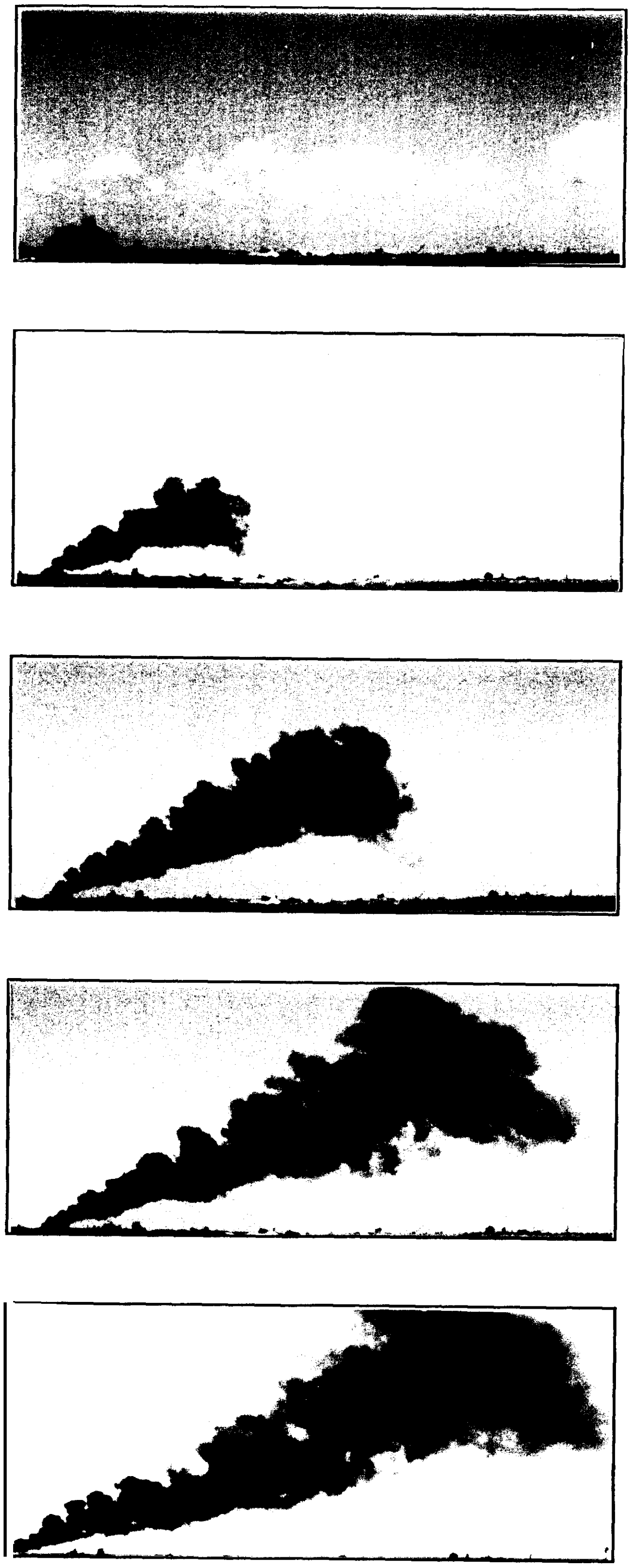
The extreme aspect ratio of the height and downrange extent of the plume and the distance from the camera to the base of the fire directly affect the resolution of the video image. One means of increasing the resolution would be to adapt relatively sophisticated lens technology to minimize the effects of the aspect ratio, therefore reducing the camera distance and increasing the relative accuracy of the scale ratio. Another approach would be to improve the resolution of the digitizing package.

An additional concern associated with the camera distance to downrange viewing distance ratio of 1:1 is related to estimates of plume volume and trajectory based on the centerline calculation method. The accuracy of the results based on the centerline calculation is reduced as the scaling factor is increased (e.g., meters per pixel). And, at considerable increases in scaling factor, results may be erroneous. For example, if the scale is 100 meters per pixel and the distance is such that the plume is measured at two pixels wide, the program cannot obtain a true centerline and will default to either one pixel position or the other. This problem can be illustrated by again referring to the images for Test 7 (see Appendix B). If the images for the upwind and crosswind camera locations are examined during the initial growth of the plume, the relatively small image produced by the crosswind camera location results in underestimation of the plume dimensions by the centerline method. The two-camera method is also affected in that the resolution of the video monitor limits the grid size for the upwind camera location. When the elliptical sections are calculated with the two-camera method, the volumes are overestimated due to overestimation of the plume width from the upwind camera.

7.2 Visual Comparison (Overall Size and Shape)

During Test 7, still photographs were taken at one-minute intervals to serve as a comparison to the video film footage recorded perpendicular to the direction of the wind (Fig. 11). The videotape was then analyzed using the computer program at the same times the still photographs were taken to serve as a side-by-side comparison. The raw data (bit maps) were printed for the first five minutes of the test in one-minute intervals as shown in Fig. 12. The two figures are shown side-by-side in Fig. 13.

As shown in Fig. 13, the image the computer/operator has determined to be smoke is in reasonable agreement with the still photographs. The only visual difference between the two image techniques is a roughness around the edges of the computer image which is a function of the resolution of the video digitizing board. The resolution of the board views the video image as a 512 x 512 matrix of pixels. During the initial stages of the fire, the smoke plume may only fill a small percentage of the screen. As previously discussed, when the image is small, the resolution of the system is more likely



Elapsed Time = 1:00 **Min.**

Elapsed Time = 2:00 **Min.**

Elapsed Time = 3:00 Min.

Elapsed Time = 4:00 Min.

Elapsed Time = 5:00 Min.

Fig. 11 - **Photographic sequence of smoke plume development at one minute intervals (Test 7)**

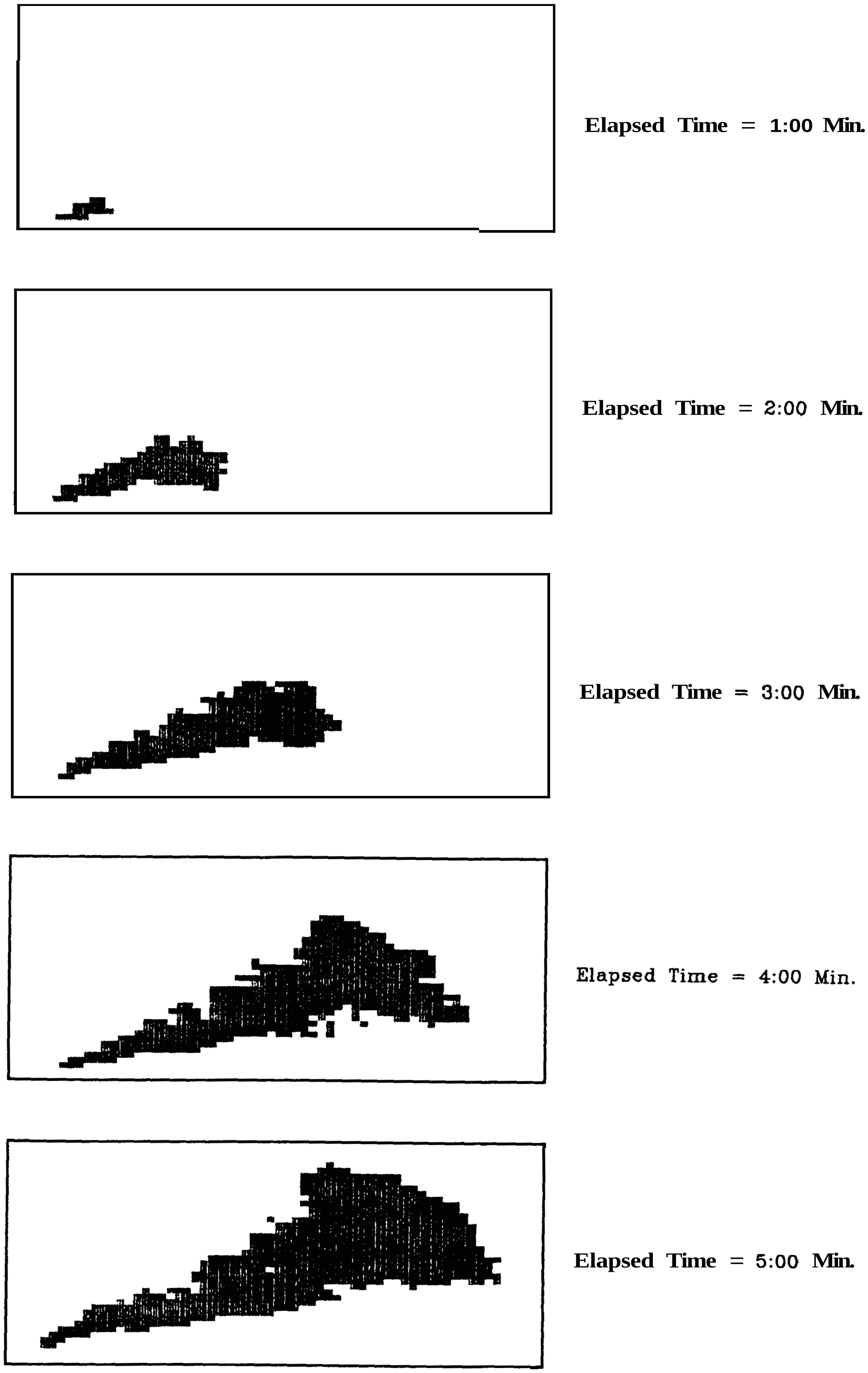


Fig. 12 - Digitized plume images at one minute intervals (Test 7)

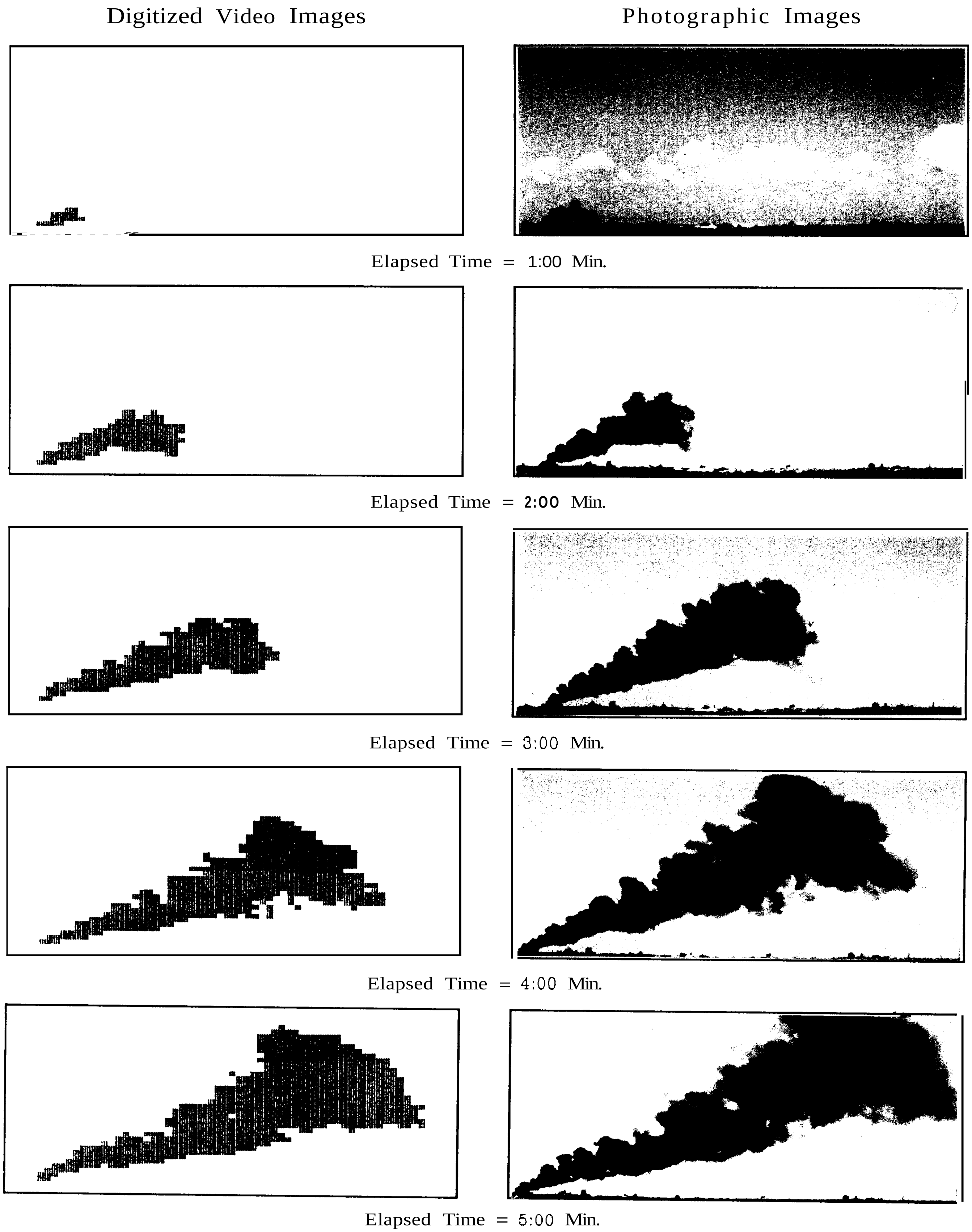


Fig. 13 - Comparison of photographic and digitized video plume images at one minute intervals (Test 7)

to alter the accuracy of the results. **As** the smoke volume increases, effects of resolution dramatically decrease.

7.3 Size/Distance Comparison

Evaluating the relative accuracy of this model was difficult given that no accepted reference data were available. However, a comparison was made of the location of the smoke plume at a set time into the fire. During Test 7, the wind direction tracked down the center of the shipping channel leading into downtown Mobile. Just downwind in the shipping lane from Little Sand Island is Mobile Shipyard. Mobile Shipyard contains numerous towers and cranes which served as good reference points in estimating the actual distance downstream the smoke had traveled. The crane selected as a reference location is a huge four-mast assembly used to load "C" containers onto cargo ships. Using the navigational charts of Mobile Bay, the crane was determined to be located approximately 1250 m from the fire location. The video footage and the still photographs both support that the plume was directly above the crane six minutes into Test 7. The trajectory data for Test 7 at the six-minute mark (Appendix B) indicates that the leading edge of the plume was located 1126 m downwind of the fire. This corresponds to an error of roughly 10%. Given the magnitude of contributing factors used to conduct this analysis, an error of 10% is viewed as quite acceptable.

8.0 SUMMARY AND CONCLUSIONS

The absence of a validated, global scale numerical code that can readily predict both near-field and far-field effects for burning crude oil on water enhances the need for a set of large scale experimental estimates of selected plume parameters. **A** set of experimental estimates are needed in order to validate newly developed models or existing models that have been extensively modified.

A computer based field scale method was developed and evaluated for obtaining such estimates. The two-camera approach appeared to provide the most accurate estimates, but may be difficult to employ due to the sensitivity to camera location. While the single-camera approach may sacrifice some accuracy, it is significantly more attractive from a field implementation standpoint.

The image digitizing technique and the computer program perform satisfactorily, providing an MS-DOS based, interactive user tool. The program is menu driven and permits modifications or corrections to video images produced by discrete pattern recognition. It has been made as user-friendly as possible, but some experience in its use is still recommended. Program documentation is provided in Appendix C. In addition, a detailed user's manual is provided in Appendix D along with a sample printout and summary data file.

Prior to implementation of this methodology, a series of tests should be performed to evaluate accuracy. One approach would be to conduct a series of test with a fixed object of known size over a range of distances consistent with downrange distances associated with model validation. It should be understood that these distances are limited relative to desired accuracy. Such an effort would provide estimates of accuracy related to image size and camera distance.

The following conclusions are drawn based on the limited mid-scale testing and evaluation of a smoke plume imaging technique:

1. visible smoke plumes from large, open burning can be characterized in terms of geometry and extent with available imaging technology;

2. comparisons of digitized images and corresponding 35 mm photographs indicate acceptable agreement in qualitative terms of plume shape, size, and downrange trajectory;

3. the lens' focal characteristics for the cameras selected for this effort (high resolution 8 mm) resulted in a 1:1 ratio of camera distance to the fire location and downrange field of view. For example, if one desires to

monitor the smoke plume geometry for 1 km downrange, the crosswind camera must be positioned at least 1 km from the fire location;

4. the quality of field measurements is dependent on site availability and weather conditions;

5. the results of this effort are limited to plume images no more than 1.8 km (~1 mile) in downrange extent. Longer distances can be evaluated, but at additional loss in resolution; and

6. the methodology is suitable for obtaining a set of data for comparison with output from computational models developed to predict smoke plume characteristics. However it is recommended that the accuracy of the method be evaluated against large objects of known size beforehand in order to determine acceptable field measurement limits.

9.0 REFERENCES

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10.0 Acknowledgements

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Our appreciation is extended to Mr. Ed Tennyson of MMS, and to Dr. David Evans and Mr. William Walton of NIST for their assistance in planning and conducting the tests and providing experimental results needed in developing this capability.

Appendix A
Equipment List

Equipment List

	Serial No.
1. Sony EVO-9100 Hi 8 mm video camera	202909
2. Sony EVO-9100 Hi 8 mm video camera	202904
3. (8) battery pack NP774	
4. (2) AC power adapter AC-V30	
5. (2) AV connecting cord (2 phono to 2 phono)	
6. (2) connecting cord with connectors (4-pin mini-DIN to 4-pin mini-DIN)	
7. (2) shoulder mount	
8. (2) hand grip	
9. (2) Ambico - video closeup/wideview lens	V0311
10. (2) Silva compass	
11. (2) Polycast protractor	
12. Sony EVO-9500 Hi 8 mm video playback unit	100058
13. Truevision VID I/O video conversion box	V1004902
14. Sony Trinitron color monitor	2655
15. 20 mHz Intel 80386-based MS-DOS computer	2909
16. Data Translations 2871-HSI video digitizing card	
17. Relysis VGA monitor	
18. Ranging Rangematic 1200	

Appendix B

Individual Test Results

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 1
DATE OF TEST : 4/16/91
TIME OF TEST : 10:00

TEST DESCRIPTION : 20 FT BY 20 FT POOL FIRE

WIND SPEED : 1.3 m / sec
WIND DIRECTION : 170 degrees

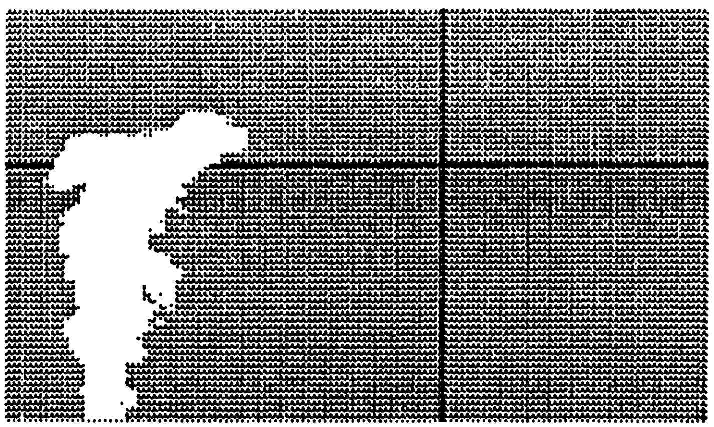
FRONT VIEW CAMERA DIRECTION : 90 degrees
FRONT VIEW CAMERA DIS NCE : 120 m
SIDE VIEW CAMERA DIRECTION : 0 degrees
SIDE VIEW CAMERA DISTANCE : 120 m

TEST LENGTH : 60 seconds
TIME STEP : 30 seconds

TEST NUMBER : 1
ELAPSED TIME : 00:30

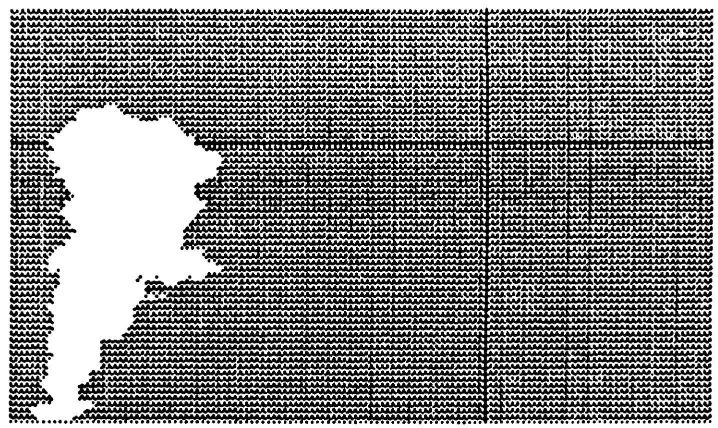
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	120	118	METERS
MAX. DISTANCE :	41	11	METERS
VOLUME OF SMOKE :	42915	44082	CU. METERS
PRODUCTION RATE :	85831	88165	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 1
ELAPSED TIME 00:30

COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
,2096112	6,670783
,4192271	13.3498
.6288431	20 ,03703
.838459	26,7325
1.04807	33.43619
1,257686	40,14809
2.096145	47 ,79309
2 ,934599	55,47512
3.773059	63,19416
4.611518	70.95023
5 ,449972	78,74332
6,288431	86.57344
6.288431	86.57344
7.12689	91.88812
7 ,965344	97.22748
8.803802	102.5915
9.642261	107,9803
10.48072	113,3937
11.31918	118,8318

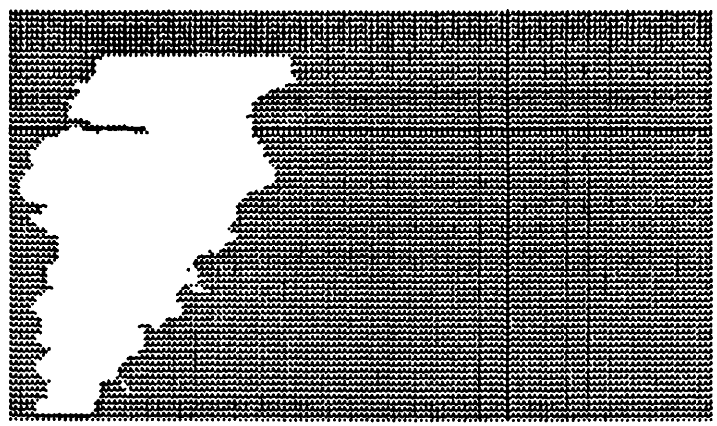
TEST NUMBER : 1
ELAPSED TIME : 01:00

	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	120	120	METERS
MAX. DISTANCE :	53	11	METERS
VOLUME OF SMOKE :	115457	118595	CU. METERS
PRODUCTION RATE :	145083	149025	CU. METERS PER MINUTE

LINES = 100 m

CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 1
ELAPSED TIME 01:00

COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
,2096112	6.670783
,4192271	13,3498
,6288431	20,03703
.838459	26,7325
1,04807	33,43619
1,257686	40,14809
2,934604	46.22927
4-611518	52,36804
6.288436	58.5644
7,965354	64,81836
9,642271	71.12989
11,31918	77,49897
11,37158	86,12283
11,42398	94,74928
11.47639	103,3783
11,52879	112.0098
11.58119	120,644

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 2
DATE OF TEST : 4/17/91
TIME OF TEST : 10:00

TEST DESCRIPTION : 20 FT BY 20 FT POOL FIRE

WIND SPEED : 2 m / sec
WIND DIRECTION : 108 degrees

FRONT VIEW CAMERA DIRECTION : 75 degrees
FRONT VIEW CAMERA DISTANCE : 650 m
SIDE VIEW CAMERA DIRECTION : 330 degrees
SIDE VIEW CAMERA DISTANCE : 120 m

TEST LENGTH : 600 seconds
TIME STEP : 120 seconds

TEST NUMBER : 2
ELAPSED TIME : 02:00

	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	250	197	METERS
MAX. DISTANCE :	154	73	METERS
VOLUME OF SMOKE :	874944	519602	CU. METERS
PRODUCTION RATE :	437472	259801	CU. METERS PER MINUTE

LINES = 100 m

CAMERA #1

LINES = 100 m

CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 2
ELAPSED TIME 02:00

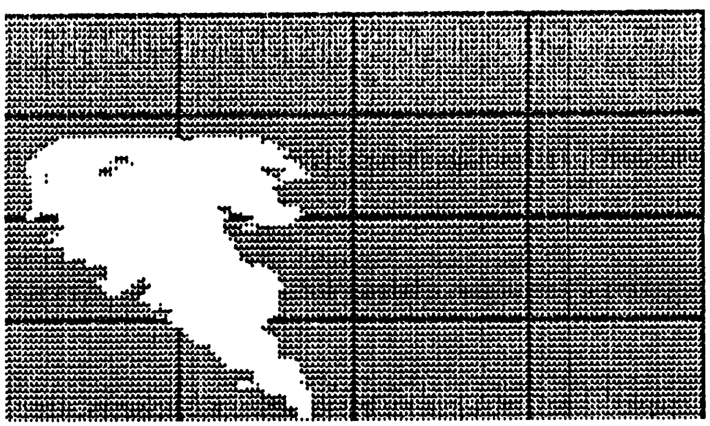
COMPASS HEADING 290 degrees

DISTANCE (Mi	HEIGHT (M)
0	0
6.250551	12,50204
12.5011	25.00817
18.75165	37,51838
25,0022	50,03268
31.25275	62.55104
37,5033	75.0735
37,5033	75,0735
44,79562	99.59559
52.08792	124.127
59.38024	148,6678
66,67255	173.218
73,96486	197,7774

TEST NUMBER : 2
ELAPSED TIME : 04:00

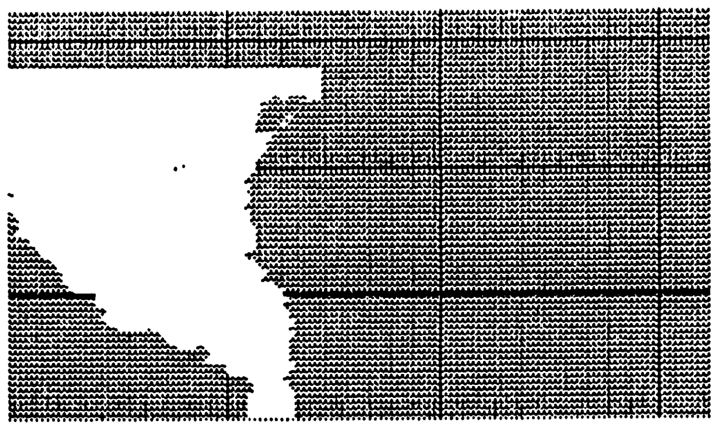
	TWO VIEW A PROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	270	254	METERS
MAX. DISTANCE :	154	83	METERS
VOLUME OF SMOKE :	1886925	1263449	CU. METERS
PRODUCTION RATE :	505990	371923	CU. METERS PER MINUTE

LINES = 100 E



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME [illegible]

TEST NUMBER 2
ELAPSED TIME [illegible]

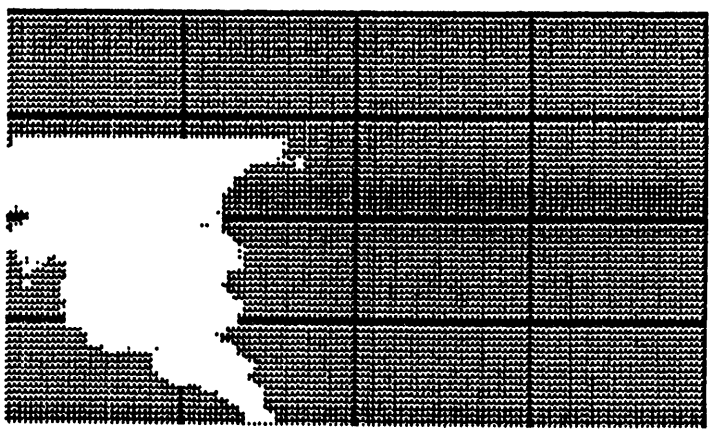
COMPASS HEADING [illegible]

DISTANCE (M)	HEIGHT (M)
0	0
4.167042	10,41781
8.334084	20.83789
12.5011	31.26024
16,66814	41.68485
20,83518	52.11173
25,00219	62,54084
31.25275	77.1463
37.50332	91.75653
43,75386	106.3715
50.00443	120,9913
56,25498	135.6158
62,5055	150.245
66.67255	171.131
70.83957	192,0214
75.00661	212,9165
79,17365	233.816
83.34068	254,7201

TEST NUMBER : 2
ELAPSED TIME : 06:00

	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	270	278	METERS
MAX. DISTANCE :	160	75	METERS
VOLUME OF SMOKE :	2421201	2276197	CU. METERS
PRODUCTION RATE :	267137	506374	CU. METERS PER MINUTE

LINES = 100 E



CAMERA #1

LINES = 100 E

CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 2
ELAPSED TIME 06:00

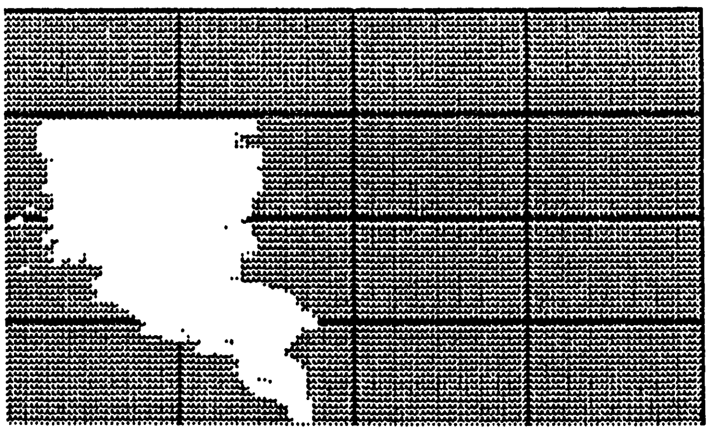
COMPASS HEADING 290 degrees

DISTANCE (M)	HEIGHT (M)
0	0
4.167042	8,334257
8.334084	16.67033
12.50113	25.00822
16.66817	33.34791
20.83521	41.68943
25.0022	50.03268
31.25275	62.55104
37.5033	75.0735
43.75385	87.60001
50,00441	100.1307
56.25495	112.6654
62,5055	125.2042
62.5055	125.2042
64.58902	150.7749
66.67253	176.3484
68.75606	201.9247
70.83956	227.5036
72.9231	253.0854
75.00661	278.6701

TEST NUMBER : 2
ELAPSED TIME : 00:00

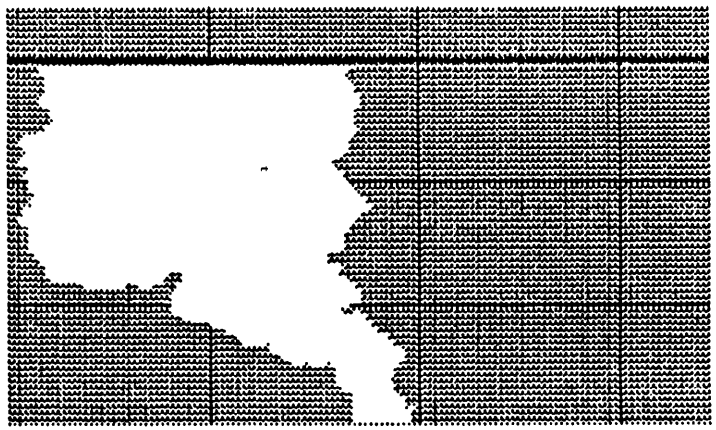
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	290	294	METERS
MAX. DISTANCE :	168	90	METERS
VOLUME OF SMOKE :	2700370	2005901	CU. METERS
PRODUCTION RATE :	139584	-135149	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 10[illegible] m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 2
ELAPSED TIME 08:[illegible]

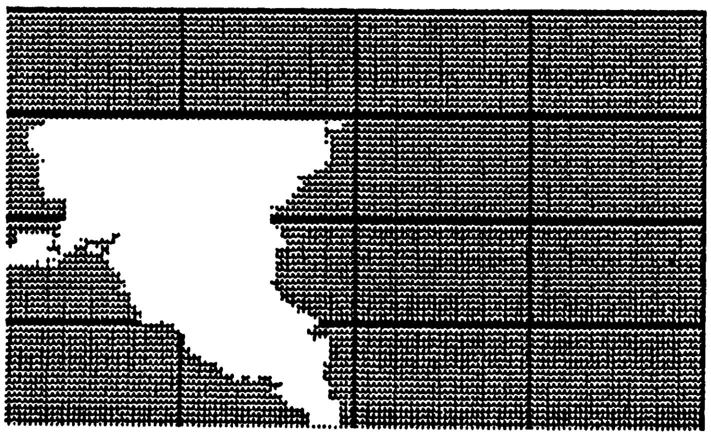
COMPASS HEADING 290 degrees

DISTANCE (M)	HEIGHT (M)
0	0
4,167042	12,50136
8.334059	25.00545
12.5011	37,51225
16.66814	50.02178
20.83516	62,53403
25.0022	75.04901
25.0022	75.04901
33,33627	89,66139
41.67036	104,2801
50.00443	118.9052
58.33851	133.5367
66.67258	148.1745
75,00661	162.8185
77.611	184,7489
80.2154	206.6823
82.81979	228.6187
85.42419	250,5581
88,02859	272.5003
90,63298	294.4458

TEST NUMBER : 2
ELAPSED TIME : 10:00

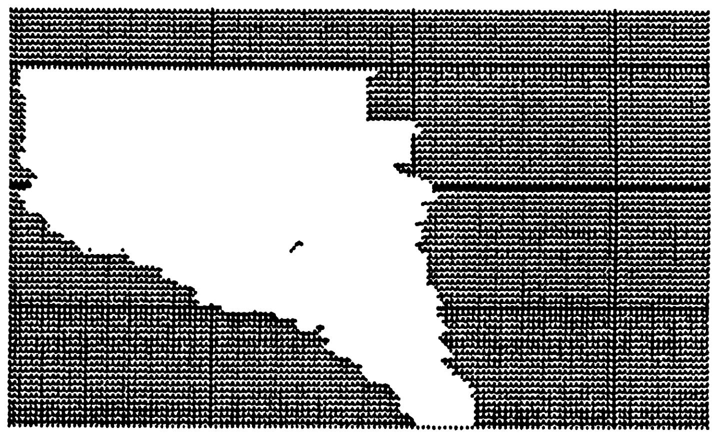
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	290	294	METERS
MAX. DISTANCE :	204	87	METERS
VOLUME OF SMOKE :	3598465	2797969	CU. METERS
PRODUCTION RATE :	449047	396034	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER *2*
ELAPSED TIME 10:00

COMPASS HEADING 290 dearees

DISTANCE (M)	HEIGHT (M)
0	0
10,41759	20.83902
20,83518	41,68939
31.25278	62,55109
41.67037	83,42415
52,08796	104,3085
62,5055	125,2042
66,67253	153,3918
70.83957	181,5855
75,00661	209,7854
79.17363	237,9913
83.34068	266,2034
87.5077	294.4216

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 3
DATE OF TEST : 5/16/91
TIME OF TEST : 10:00

TEST DESCRIPTION : 20 FT BY 20 FT POOL FIRE

WIND SPEED : 3.3 m / sec
WIND DIRECTION : 160 degrees

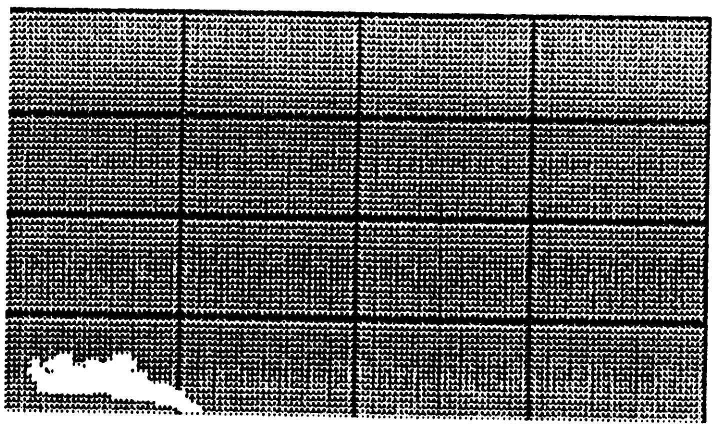
FRONT VIEW CAMERA DIRECTION : 90 degrees
FRONT VIEW CAME A DISTANCE : 650 m
SIDE VIEW CAMERA DIRECTION : 30 degrees
SIDE VIEW CAMERA DISTANCE : 950 m

TEST LENGTH : 120 seconds
TIME STEP : 30 seconds

TEST NUMBER : 3
ELAPSED TIME : 00:30

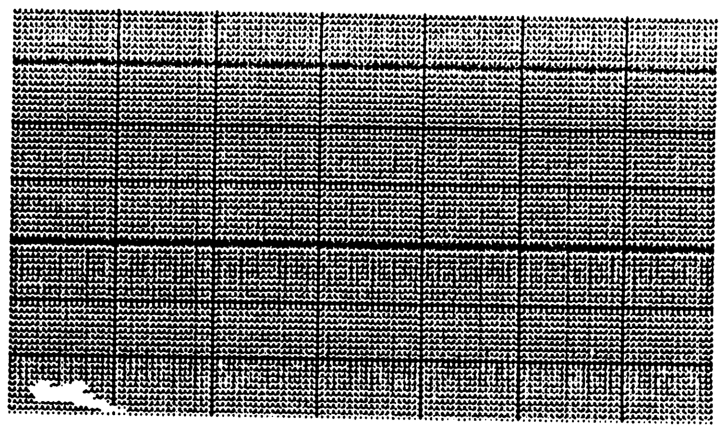
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	60	43	METERS
MAX. DISTANCE :	69	109	METERS
VOLUME OF SMOKE :	100603	72903	CU. METERS
PRODUCTION RATE :	213206	145806	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TR[illegible]

TEST NUMBER 3
ELAPSED TIME 00:30

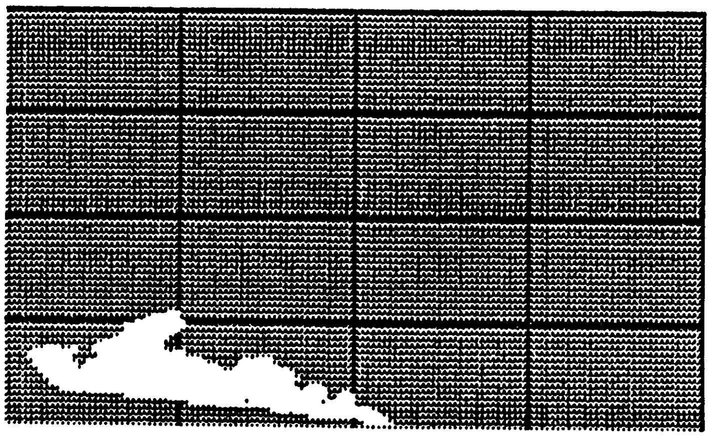
COMPASS HEADING 340 [illegible]

DISTANCE (M)	HEIGHT (M)
0	0
8.076092	4.208642
16.15218	8.501218
24.22828	12.07773
32.30437	17m33818
40.38046	21.88255
48.45643	26.51082
60.57057	29.68941
72m68473	32.9467
84.79888	36.28268
96.91302	39.69735
109.0272	43m19071

TEST NUMBER : 3
ELAPSED TIME : 01:00

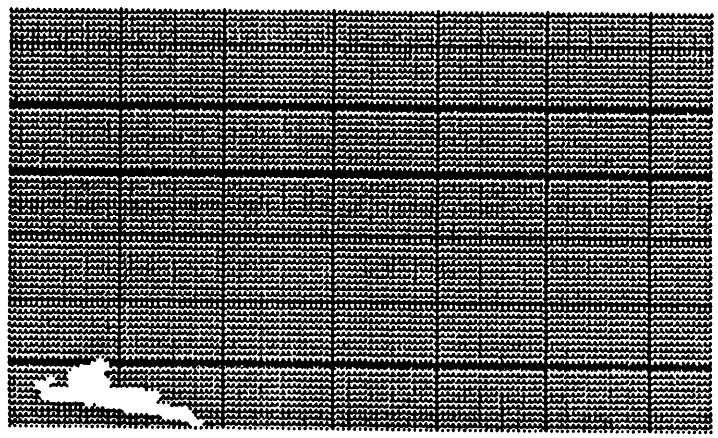
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	110	86	METERS
MAX. DISTANCE :	150	258	METERS
VOLUME OF SMOKE :	478418	296866	CU. METERS
PRODUCTION RATE :	743630	447926	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 3
ELAPSED TIME 01:00

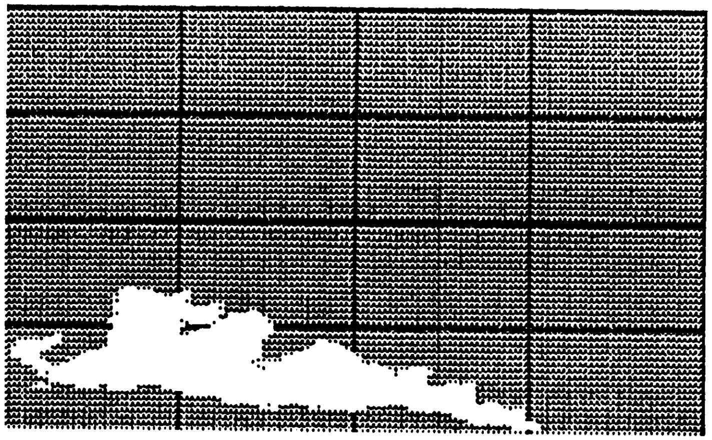
COMPASS HEADING 340 degrees

DISTANCE (Mi	HEIGHT (M)
0	0
18.84417	6.396885
37.68837	13.08754
56,53253	20.07196
75.3767	27.35016
94.22089	34,92212
113.0651	42,78785
113.0651	42.78785
137.2933	49.41108
161.5215	56,31759
185.7497	63.50737
209.978	70,98043
234.2062	78.73677
258.4345	86,77639

TEST NUMBER : 3
ELAPSED TIME : 01:30

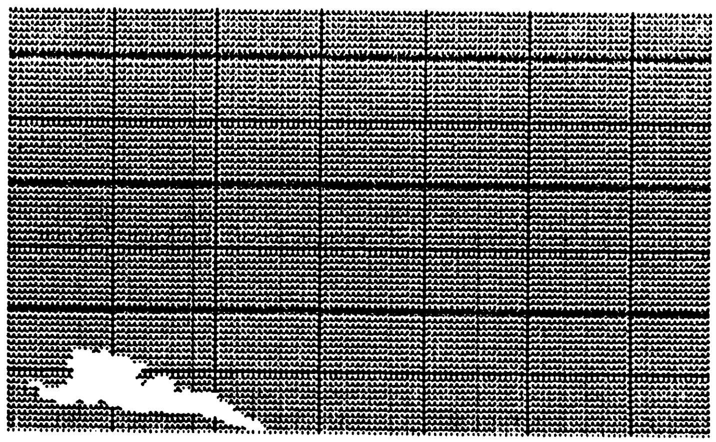
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	130	122	METERS
MAX. DISTANCE :	222	298	METERS
VOLUME OF SMOKE :	1278089	726433	CU. METERS
PRODUCTION RATE :	1599343	859133	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 3
ELAPSED TIME 01:30

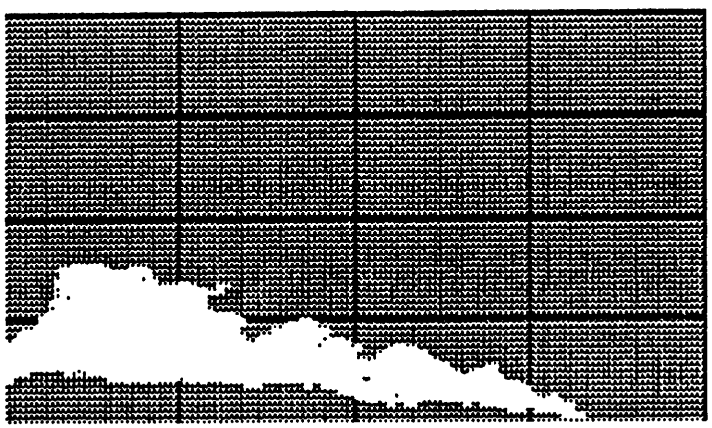
COMPASS HEADING 340 degrees

DISTANCE (M)	HEIGHT (M)
0	0
16.15215	6.375901
32.30431	13.0036
48.45646	19.88311
64.60861	27.01442
80.76076	34.39753
96.91292	42.03244
96.91289	42.03244
137.2933	56.12123
177.6737	71.25921
218.0541	87.44636
258.4346	104.6827
298.815	122.9682

TEST NUMBER : 3
ELAPSED TIME : 02:00

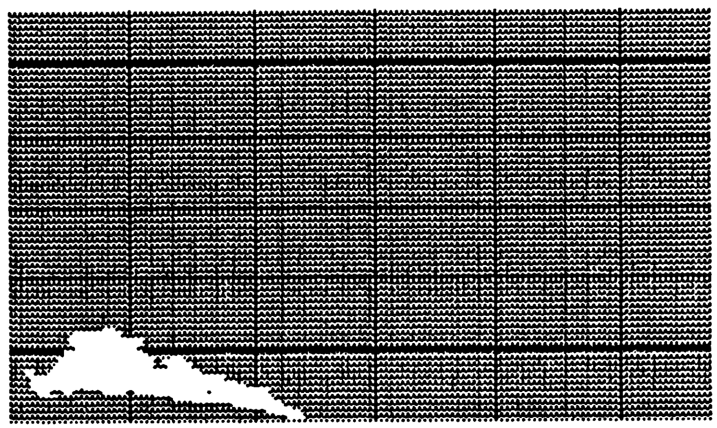
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	150	153	METERS
MAX. DISTANCE :	263	379	METERS
VOLUME OF SMOKE :	1592349	1506830	CU. METERS
PRODUCTION RATE :	628518	1560794	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 3
ELAPSED TIME 02:00

COMPASS HEADING 340 degrees

DISTANCE (M)	HEIGHT (M)
0	0
21.53621	6.417868
43.0724	13.17147
64.60861	20.26082
86.14482	27.68589
107.681	35.44671
129.2172	43.54326
129.2172	43.54326
150.7535	49.50053
172.2897	55.68162
193.8259	62.08654
215.3622	68.71529
236.8985	75.56786
258.4345	82.64418
202.6627	95.80376
306.891	109.4669
331.1193	123,6337
355.3476	138.3041
379.5758	153.4781

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 4
DATE OF TEST : 5/17/91
TIME OF TEST : 10:00

TEST DESCRIPTION : 20 FT BY 20 FT POOL FIRE

WIND SPEED : 2.7 m / sec
WIND DIRECTION : 140 degrees

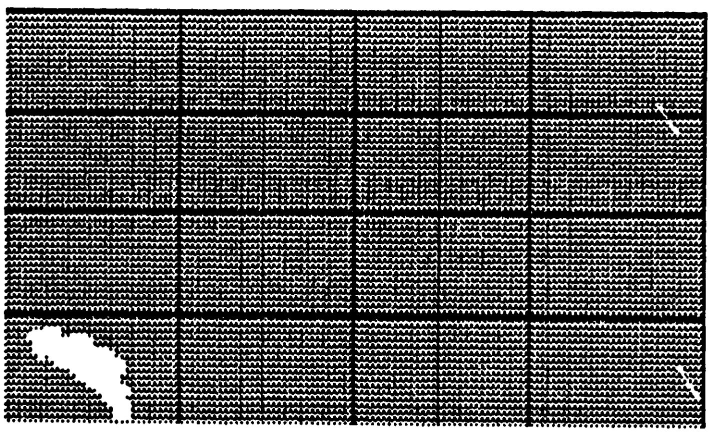
FRONT VIEW CAMERA DIRECTION : 75 degrees
FRONT VIEW CAMERA DISTANCE : 650 m
SIDE VIEW CAMERA DIRECTION : 35 degrees
SIDE VIEW CAMERA DISTANCE : 950 m

TEST LENGTH : 150 seconds
TIME STEP : 30 seconds

TEST NUMBER : 4
ELAPSED TIME : 00:30

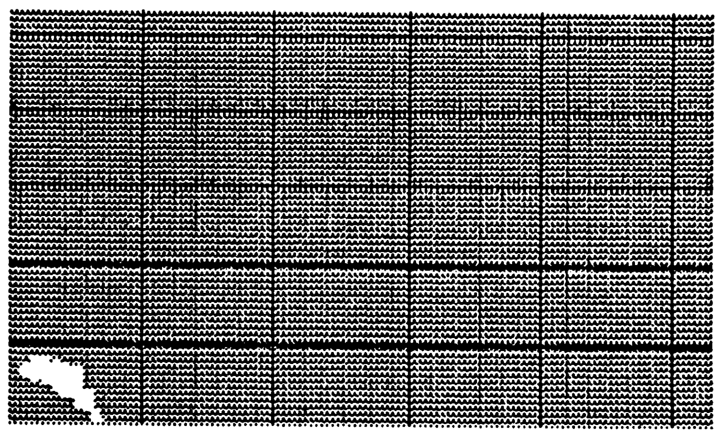
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	80	82	METERS
MAX. DISTANCE :	45	59	METERS
VOLUME OF SMOKE :	52923	42685	CU. METERS
PRODUCTION RATE :	105846	85370	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 4
ELAPSED TIME 00:30

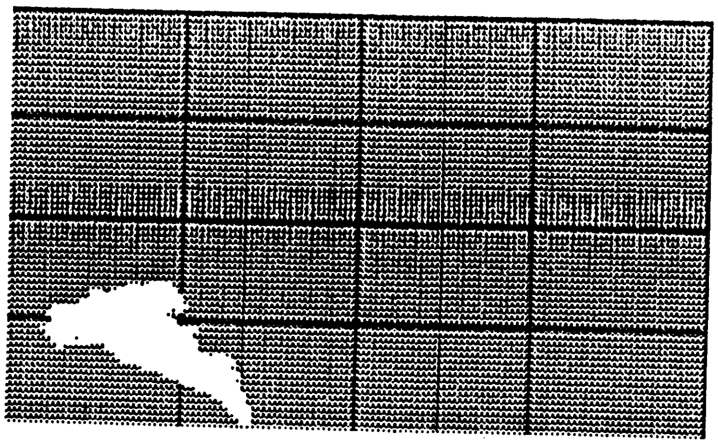
COMPASS HEADING 320 degrees

DISTANCE (M)	HEIGHT (M)
0	0
2.519672	6.789746
5.039345	13.61728
7.559016	20.48261
10.07869	27.38573
12.59836	34.32665
15.118	41.30525
23.93685	49.18707
32.75569	57.21133
41.57454	65.37803
50.39339	73.68718
59.21223	82.13877

TEST NUMBER : 4
ELAPSED TIME : 01:00

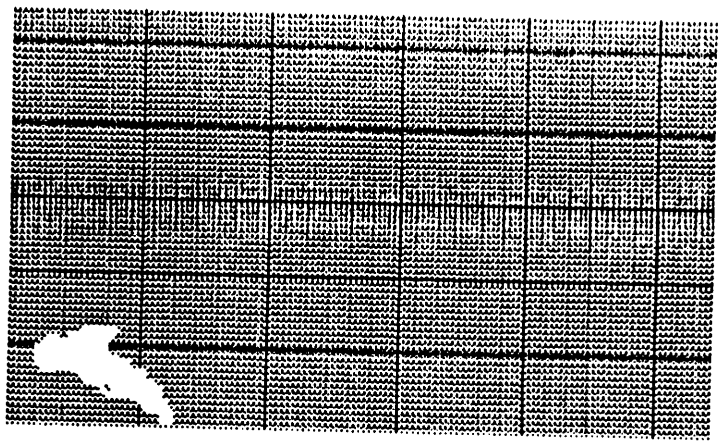
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	130	129	METERS
MAX. DISTANCE :	90	98	METERS
VOLUME OF SMOKE :	262318	330968	CU. METERS
PRODUCTION RATE :	418790	576567	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME [illegible]

TEST NUMBER 4

ELAPSED TIME 01:[illegible]

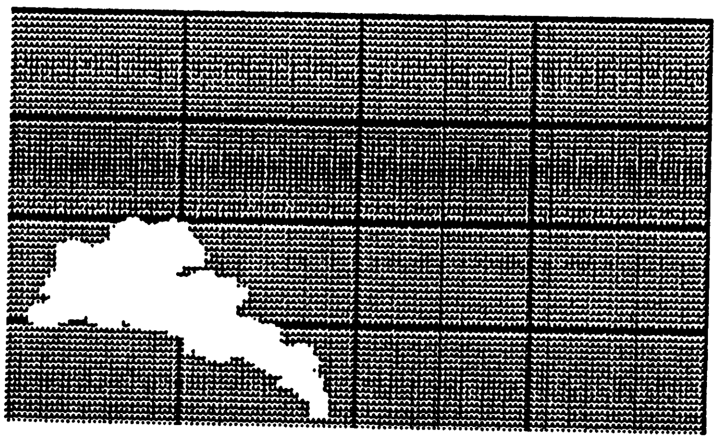
COMPASS HEADING 22[illegible] [illegible]

DISTANCE (M)	HEIGHT (M)
0	0
2.519672	6.267443
5.03933	12.56977
7.559002	18.90698
10.07867	25.27908
12.59833	31.68606
15.118	38.12793
15.118	38.12793
22.67701	44.84887
30.23601	51.67448
37.79501	58.60473
45.35401	65.63963
52.91302	72.7792
60.47202	80.02341
60.47202	80.02341
68.03103	89.61262
75.59005	99.34137
83.14906	109.2097
90.70808	119.2175
98.2671	129.3648

TEST NUMBER : 4
ELAPSED TIME : 01:30

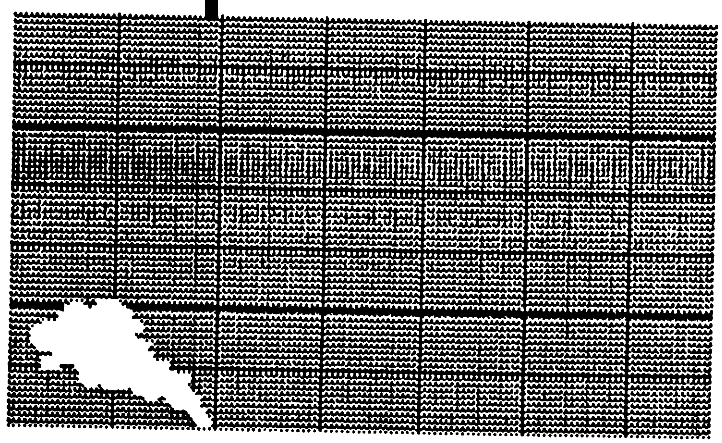
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	210	192	METERS
MAX. DISTANCE :	125	154	METERS
VOLUME OF SMOKE :	937427	872783	CU. METERS
PRODUCTION RATE :	1350217	1083630	CU. METERS PER MINUTE

LINES = 143 E



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 4
ELAPSED TIME 01:30

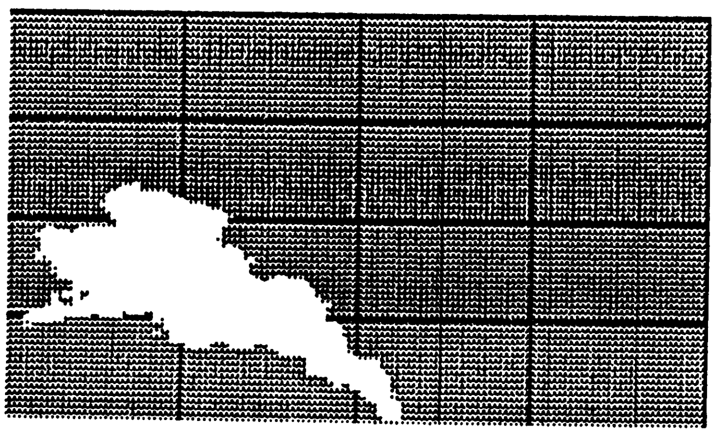
COMPASS HEADING 320 degrees

DISTANCE (M)	HEIGHT (M)
0	0
2.519658	7.834303
5.039345	15.71221
7.559002	23.63373
10.07866	31.59885
12.59835	39.60758
15.118	47.65991
15.118	47.65991
25.19669	56.7491
35.27538	66.02434
45.35408	75.48563
55.43276	85.13299
65.51145	94.96639
75.59002	104.9857
91.33795	121.5871
107.0859	138.6609
122.8338	156.207
138.5817	174.2256
154.3297	192.7166

TEST NUMBER : 4
ELAPSED TIME : 02:00

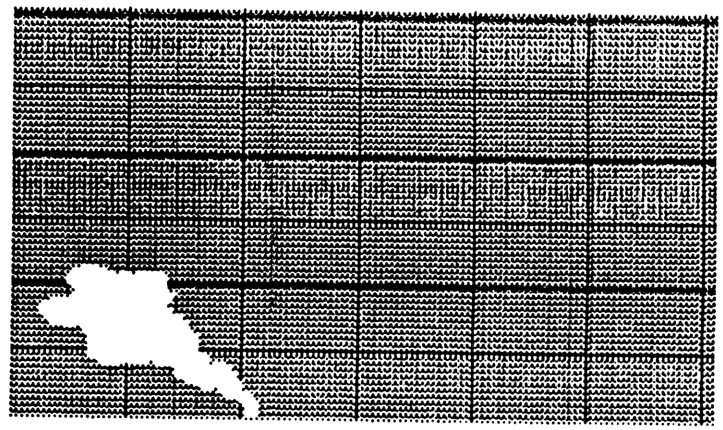
	TWO VIEW APP OACH	CENTER LINE APPROACH	
MAX. HEIGHT :	230	246	METERS
MAX. DISTANCE :	159	211	METERS
VOLUME OF SMOKE :	1333336	1787831	CU. METERS
PRODUCTION RATE :	791938	1830095	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 4
ELAPSED TIME 02:00

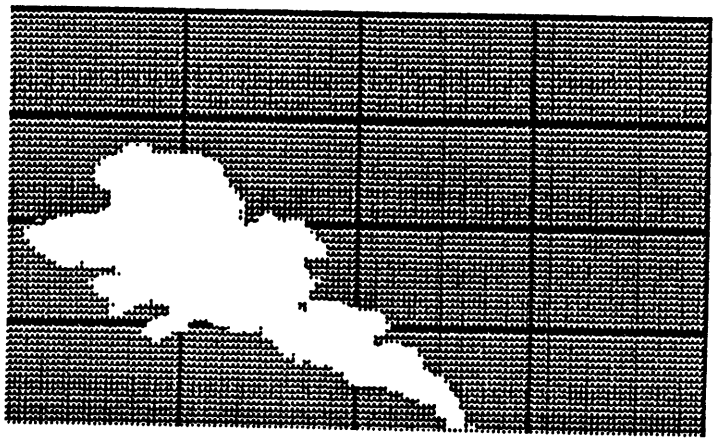
COMPASS HEADING 320 degrees

DISTANCE (M)	HEIGHT (M)
0	0
7.559032	10.50389
15.118	21.1822
22.67701	32.03494
30,23604	43.0621
37.79504	54,26368
45,35401	65.63963
60.47202	77.80055
75.59005	90,31032
90.70806	103.1689
105,8261	116.3764
120.9441	129.9327
136.062	143.8378
148,6604	160,1403
161.2587	176.7916
173.857	193,7917
186.4554	211.1407
199,0537	228,8385
211.6521	246.8852

TEST NUMBER : 4
ELAPSED TIME : 02:30

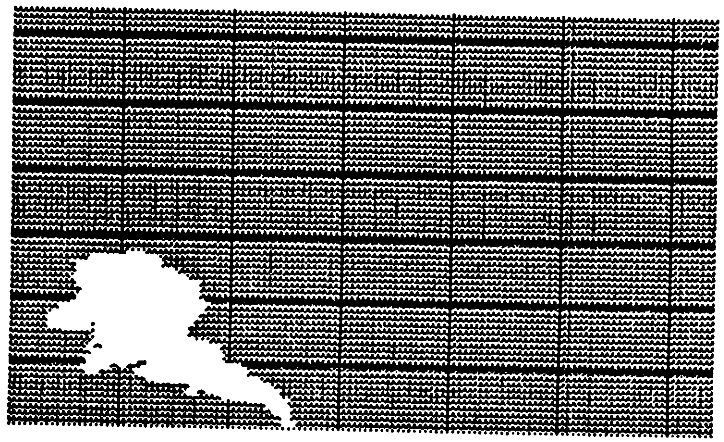
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	270	264	METERS
MAX. DISTANCE :	168	241	METERS
VOLUME OF SMOKE :	2023273	2368753	CU. METERS
PRODUCTION RATE :	1379753	1161843	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 4
ELAPSED TIME 02:30

COMFASS HEADING 320 dear-ees

DISTANCE (M)	HEIGHT (M)
0	0
5,039345	7.332374
10.07869	14.74615
15.118	22,24132
20.15735	29.81788
25m 19672	37.47585
30.23681	45.21517
46,61386	60.24962
62.99171	75.77537
79.36955	91.79242
95.7474	108.3008
112.1253	125.3004
120,503	142-7913
151.18	165.3884
173.8571	188.8227
196.5341	213.0943
219,2111	238,2031
241.8881	264.1491

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 5
DATE OF TEST : 5/28/91
TIME OF TEST : 10:00

TEST DESCRIPTION : 35 FT BY 35 FT POOL FIRE

WIND SPEED : 3.0 m / sec
WIND DIRECTION : 0 degrees

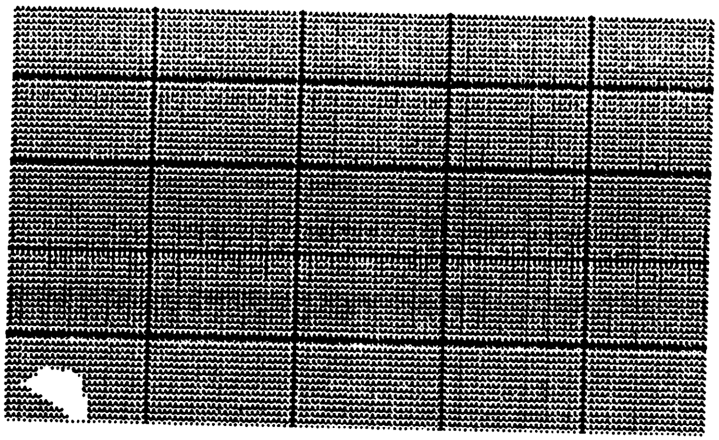
FRONT VIEW CAMERA DIRECTION : 100 degrees
FRONT VIEW CAMERA DISTANCE : 950 m
SIDE VIEW CAMERA DIRECTION : 40 degrees
SIDE VIEW CAMERA DISTANCE : 650 m

TEST LENGTH : 120 seconds
TIME STEP : 30 seconds

TEST NUMBER : 5
ELAPSED TIME : 00:30

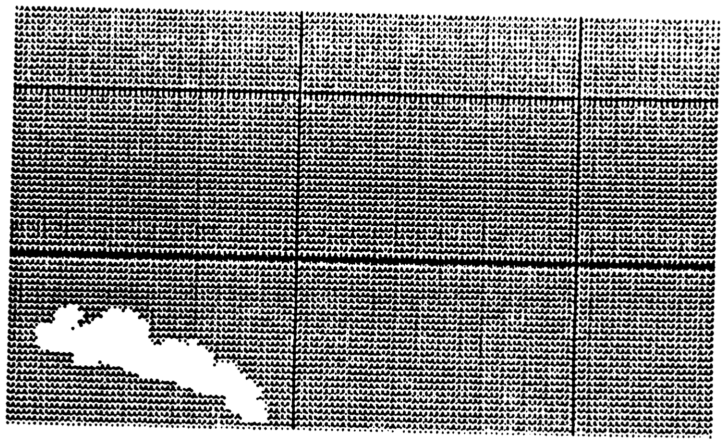
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	70	46	METERS
MAX. DISTANCE :	48	49	METERS
VOLUME OF SMOKE :	41338	73630	CU. METERS
PRODUCTION RATE :	82676	14720	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 5
ELAPSED TIME 00:30

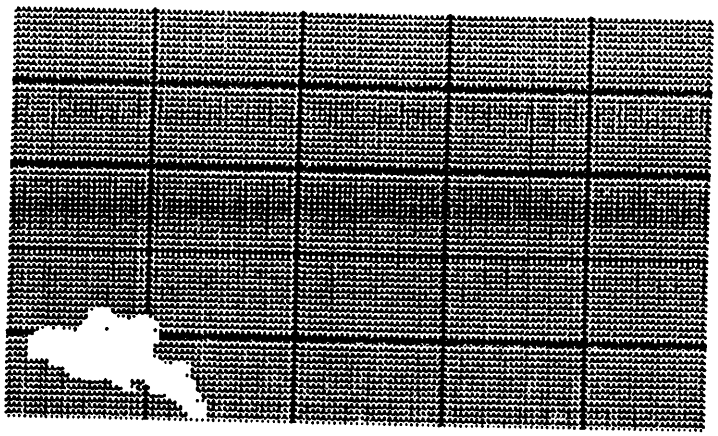
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
9.936396	8.889222
19.87281	17.9468
29.8092	27,17275
39.74561	36.56705
49.68201	46.12972

TEST NUMBER : 5
ELAPSED TIME : 01:00

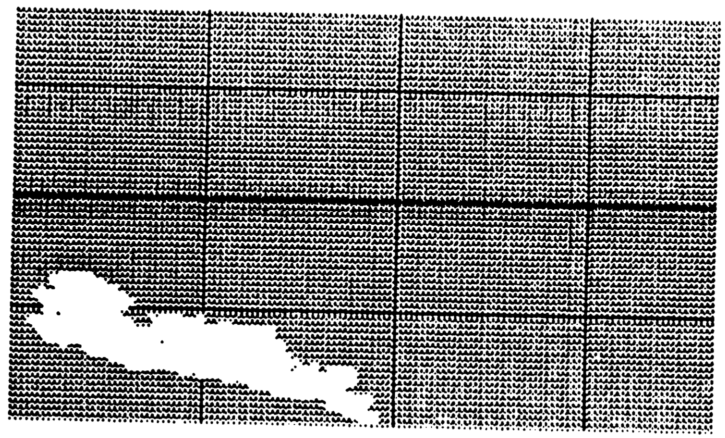
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	130	114	METERS
MAX. DISTANCE :	122	191	METERS
VOLUME OF SMOKE :	475385	541395	CU. METERS
PRODUCTION RATE :	868095	935512	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

I

PLUME TRAJECTORY

TEST NUMBER 5
ELAPSED TIME 01:00

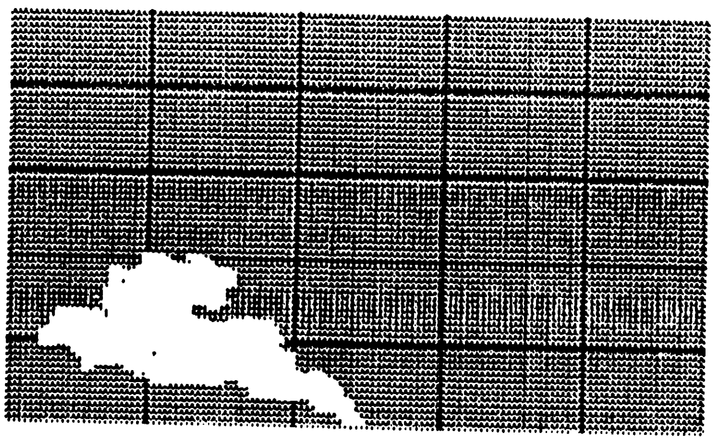
COMPASS HEADING 350 dearees

DISTANCE (M)	HEIGHT (M)
0	0
11.17844	8.899744
22.35688	17.98889
33.53535	27.26745
44.71379	36.73541
55.89225	46 ,39278
67.07063	56.23949
91.91166	67.0859
116.7527	78.3532 1
141.5937	90,04142
166.4347	102.1505
191.2757	114.6806

TEST NUMBER : 5
ELAPSED TIME : 01:30

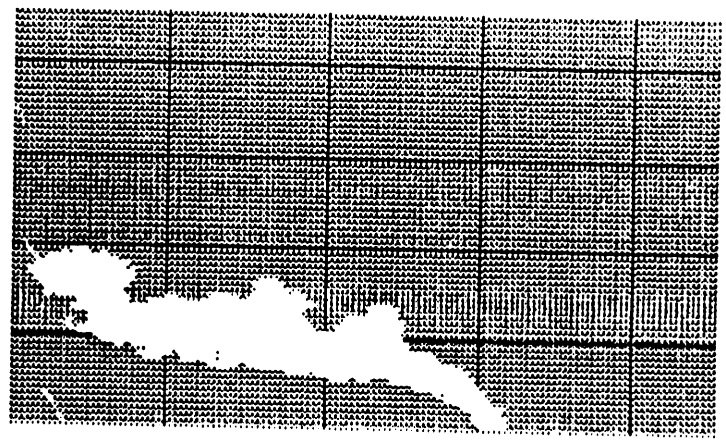
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	200	172	METERS
MAX. DISTANCE :	198	308	METERS
VOLUME OF SMOKE :	1974481	2470698	CU. METERS
PRODUCTION RATE :	2998192	3858606	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 5
ELAPSED TIME 01:30

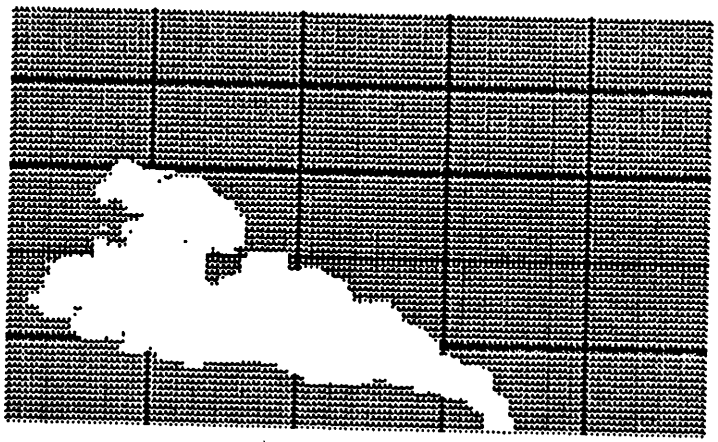
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
9.93641	7.619325
19.87276	15.38296
29.80917	23.2909
39,74558	31.34315
49,68193	39.53971
59.61834	47.88058
59,6184	47 ,88058
109.3804	69.50726
158.9824	92.81756
208.6644	117.8115
258,3464	144.489
308 ,0285	172.8501

TEST NUMBER : 5
ELAPSED TIME : 02:00

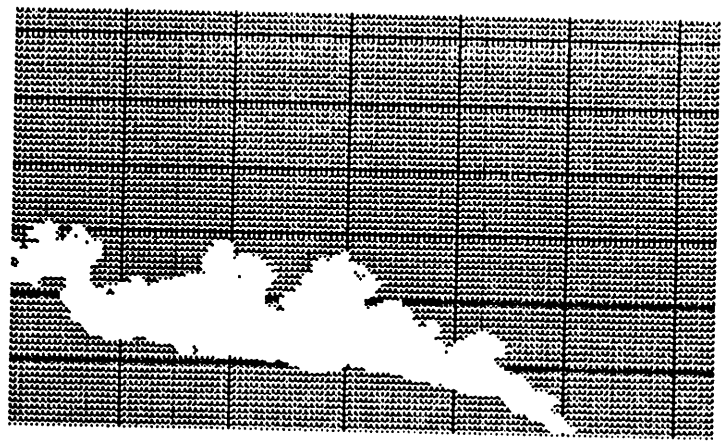
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	310	302	METERS
MAX. DISTANCE :	350	541	METERS
VOLUME OF SMOKE :	6536319	7025034	CU. METERS
PRODUCTION RATE :	9123675	9108671	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

FLUME TRAJECTORY

TEST NUMBER 5
ELAPSED TIME 02:00

CUMFRSS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
9,93641	10.15912
19.87282	20.51065
29.80923	31.0546
39.74564	41.79095
49.68205	52.71972
59,61834	63,84078
119.2367	81.3259
178.8551	100.2541
238.4735	120.6254
298.0919	142,4398
357.7103	165.6973
417.3284	190.3978
442,1694	211.5748
467.0104	233.3532
491.8514	255.7328
516.6924	278.7136
541.5333	302.2958

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 6
DATE OF TEST : 5/29/91
TIME OF TEST : 6:00

TEST DESCRIPTION : 35 FT BY 35 FT POOL FIRE

WIND SPEED : 10 m / sec
WIND DIRECTION : 200 degrees

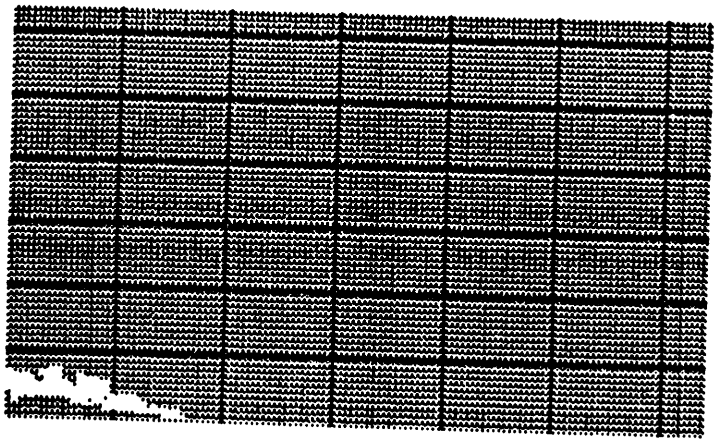
FRONT VIEW CAMERA DIRECTION : 145 degrees
FRONT VIEW CAMERA DISTANCE : 915 m
SIDE VIEW CAMERA DIRECTION : 42 degrees
SIDE VIEW CAMERA DISTANCE : 650 m

TEST LENGTH : 90 seconds
TIME STEP : 30 seconds

TEST NUMBER : 6
ELAPSED TIME : 00:30

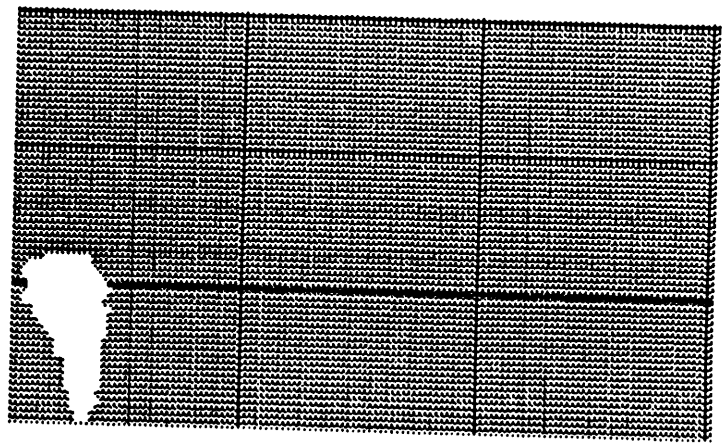
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	120	50	METERS
MAX. DISTANCE :	9≤	1≤5	METERS
VOLUME OF SMOKE :	5[illegible]838	92738	CU. METERS
PRODUCTION RATE :	113676	185477	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 6
ELAPSED TIME 00:30

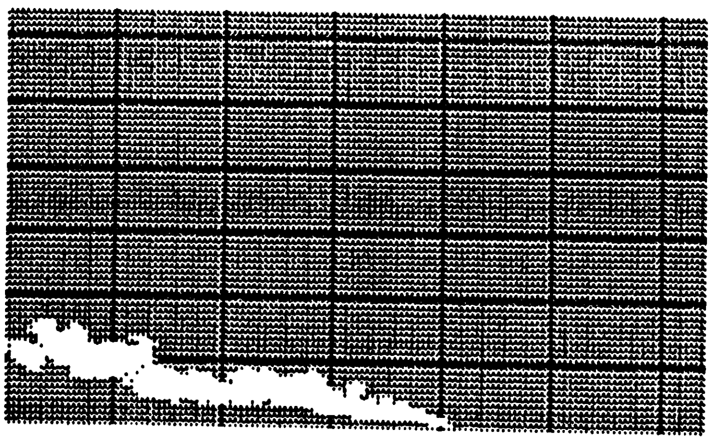
COMPASS HEADING 20 degrees

DISTANCE (M)	HEIGHT (M)
0	0
10	3
20	7
30	10
40	13
50	17
60	20
76	25
92	30
108	35
123	40
139	45
155	50

TEST NUMBER : 6
ELAPSED TIME : 01:00

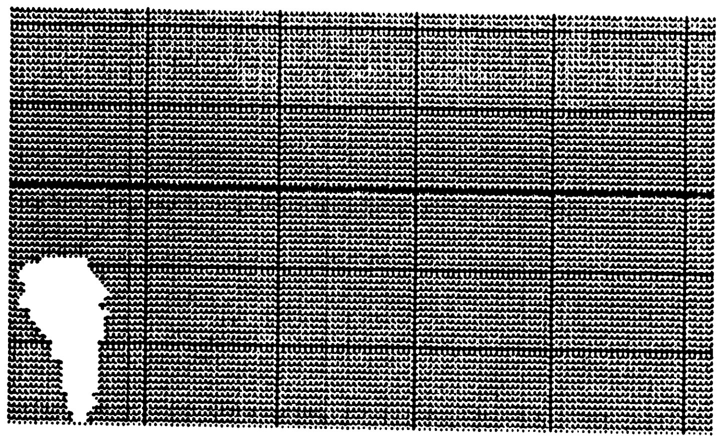
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	200	119	METERS
MAX. DISTANCE :	205	353	METERS
VOLUME OF SMOKE :	457762	395718	CU. METERS
PRODUCTION RATE :	801847	605958	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 6
ELAPSED TIME 01:00

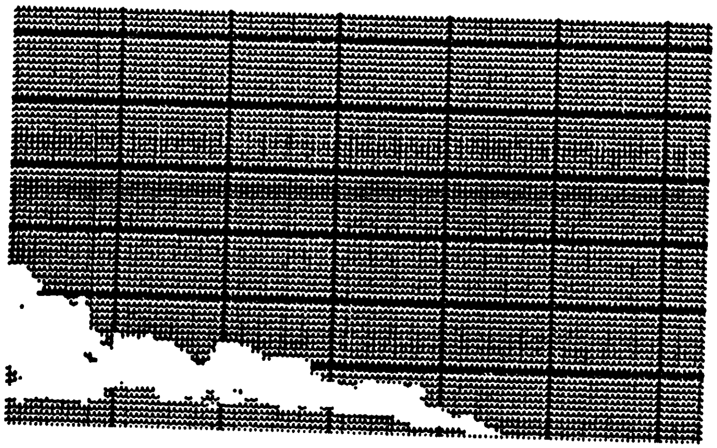
COMPASS HEADING 20 degrees

DISTANCE (M)	HEIGHT (M)
0	0
17	7
33	13
50	20
67	27
83	33
100	40
120	43
140	47
160	50
180	54
200	57
220	60
247	72
273	84
300	96
327	107
353	119

TEST NUMBER : 6
ELAPSED TIME : 01:30

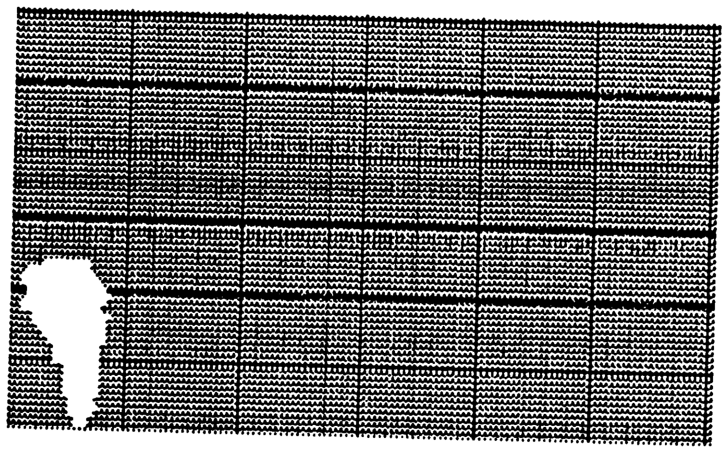
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	240	135	METERS
MAX. DISTANCE :	365	402	METERS
VOLUME OF SMOKE :	978843	1623592	CU. METERS
PRODUCTION RATE :	1042161	2455748	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

FLUME TRAJECTORY

TEST NUMBER 6
ELAPSED TIME 01:30

COMPASS HEADING 20 dearees

DISTANCE (M)	HEIGHT (M)
0	0
13	7
27	13
40	20
53	27
67	33
80	40
107	47
133	53
160	60
187	67
213	74
240	80
273	91
305	102
338	113
370	124
403	135

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 7
DATE OF TEST : 5/30/91
TIME OF TEST : 12:00

TEST DESCRIPTION : 35 FT BY 35 FT POOL FIRE

WIND SPEED : 3 m / sec
WIND DIRECTION : 170 degrees

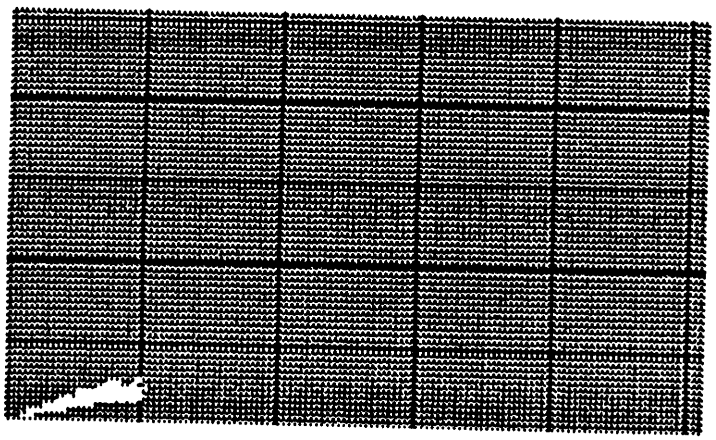
FRONT VIEW CAMERA DIRECTION : 250 degrees
FRONT VIEW CAMERA DISTANCE : 3500 m
SIDE VIEW CAMERA DIRECTION : 42 degrees
SIDE VIEW CAMERA DISTANCE : 650 m

TEST LENGTH : 600 seconds
TIME STEP : 120 seconds

TEST NUMBER : 7
ELAPSED TIME : 02:00

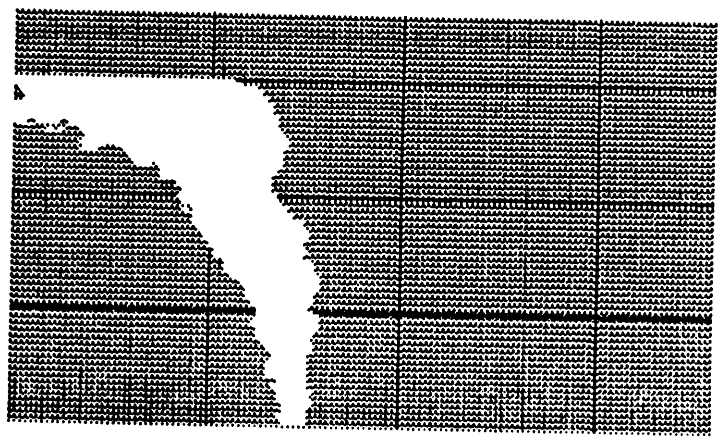
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	300	158	METERS
MAX. DISTANCE :	300	432	METERS
VOLUME OF SMOKE :	1592596	1750206	CU. METERS
PRODUCTION RATE :	796298	875103	CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 7
ELAPSED TIME 02:00

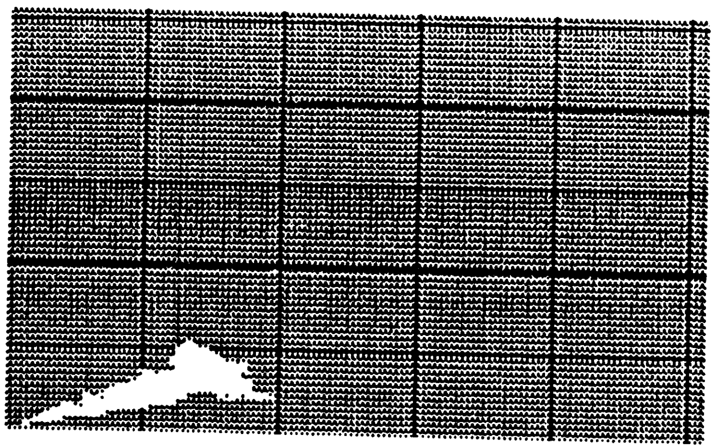
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
50	27
101	53
151	80
201	107
252	134
382	150
369	152
356	154
342	155
329	157
315	159
382	150
392	152
402	154
413	155
423	157
433	159

TEST NUMBER : 7
ELAPSED TIME : 04:00

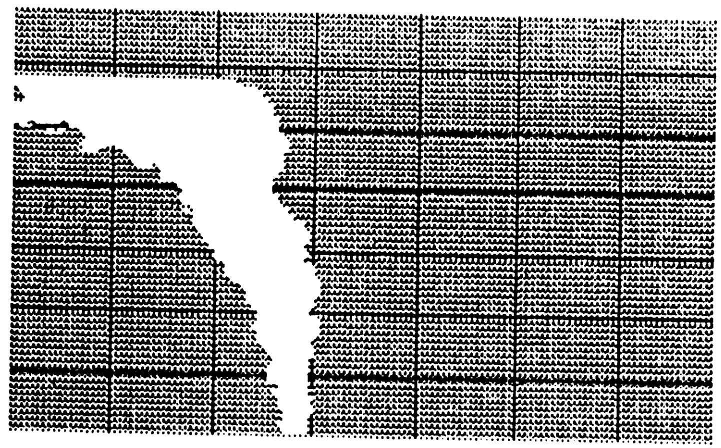
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	580	375	METERS
MAX. DISTANCE :	540	727	METERS
VOLUME OF SMOKE :	9911071	1.041545E+07	CU. METERS
PRODUCTION RATE :	4159237	4332621	CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 7
ELAPSED TIME 04:00

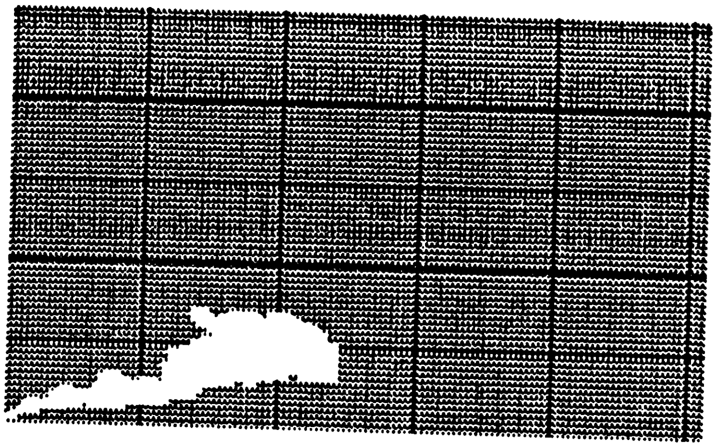
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
74	40
148	80
221	120
295	160
369	200
443	241
443	241
500	268
557	294
614	321
671	348
728	375

TEST NUMBER : 7
ELAPSED TIME : 06:40

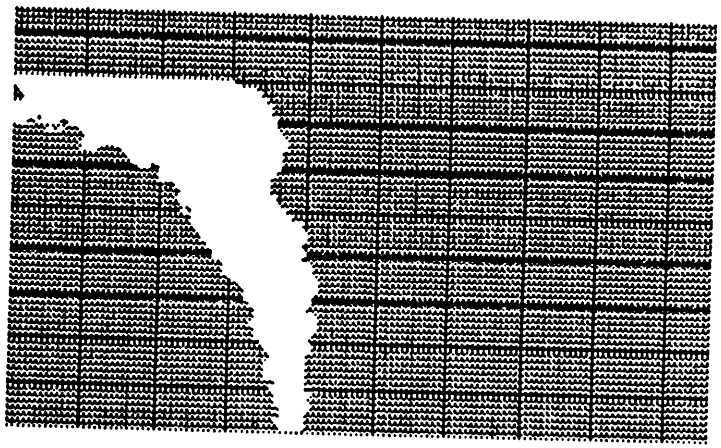
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	800	476	METERS
MAX. DISTANCE :	680	1126	METERS
VOLUME OF SMOKE :	3.242241E+07	5.772574E+07	CU. METERS
PRODUCTION RATE :	1.125567E+07	2.365515E+07	CU. METERS PER MINUTE

LINES = 500 E



CAMERA #1

LINES = 100 E



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 7
ELAPSED TIME 06:00

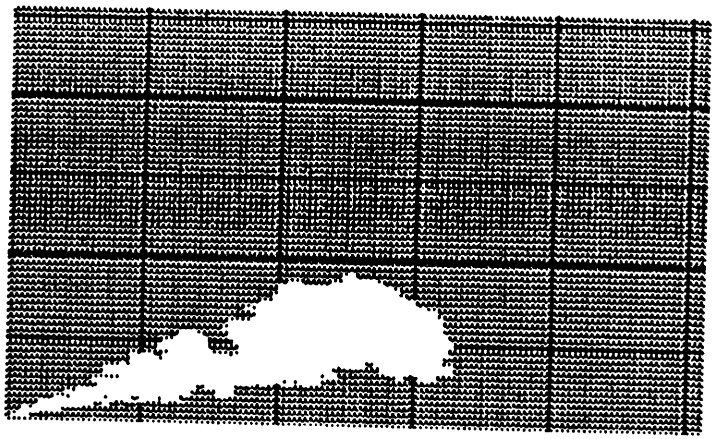
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
67	30
134	60
201	90
268	120
335	150
402	180
402	180
456	207
510	234
563	261
617	288
671	315
724	342
805	369
885	396
966	423
1046	450
1127	477

TEST NUMBER : 7
ELAPSED TIME : 08:00

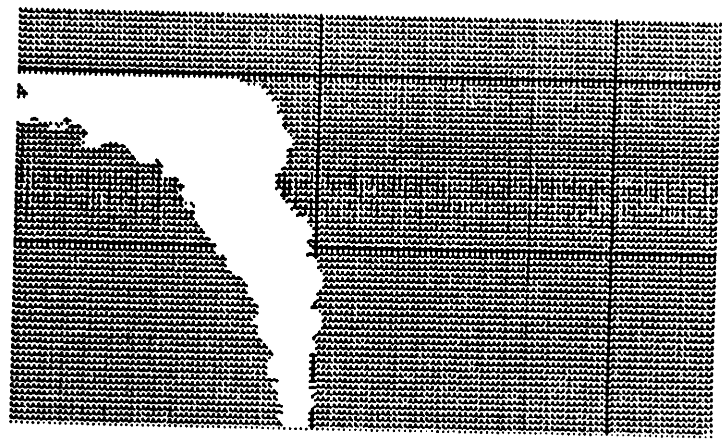
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	980	658	METERS
MAX. DISTANCE :	1140	1348	METERS
VOLUME OF SMOKE :	6.59398E+07	1.340003E+08	CU. METERS
PRODUCTION RATE :	3.29699E+07	6.700013E+07	CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 500 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 7
ELAPSED TIME 08:00

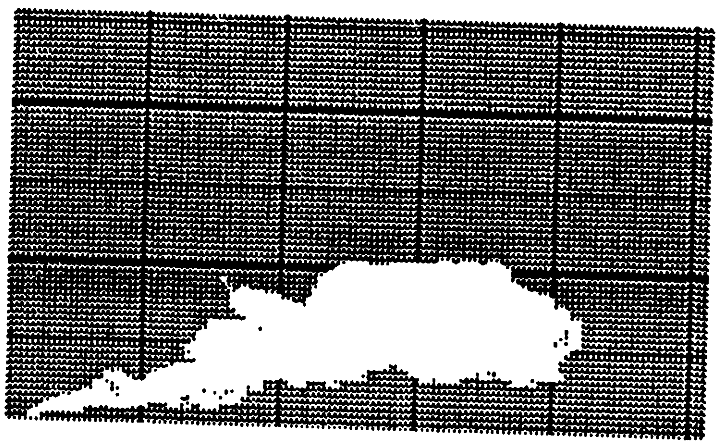
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
107	53
215	107
322	160
429	214
537	268
644	321
785	389
926	456
1067	523
1207	591
1348	659

TEST NUMBER : 7
ELAPSED TIME : 10:00

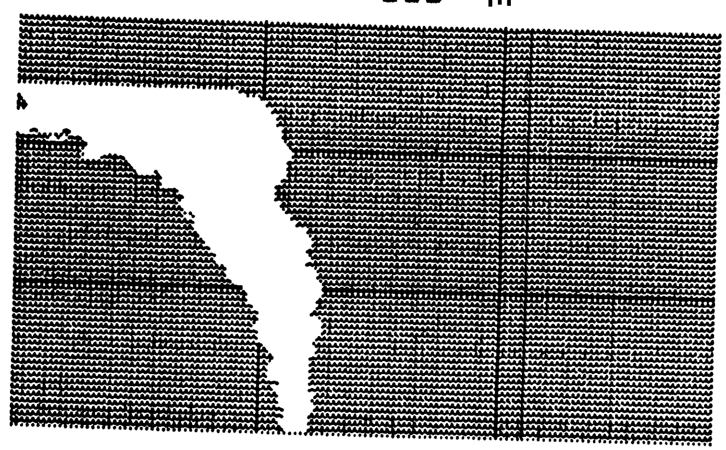
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	1200	782	METERS
MAX. DISTANCE :	1400	1824	METERS
VOLUME OF SMOKE :	1.438354E+08	3.809412E+08	CU. METERS
PRODUCTION RATE :	7.191772E+07	1.904706E+08	CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 500 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 7
ELAPSED TIME 10:00

COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
107	40
215	80
322	120
429	160
537	201
644	241
644	241
751	308
859	375
966	443
1073	510
1181	578
1288	645
1395	673
1503	700
1610	727
1717	755
1824	782

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 8
DATE OF TEST : 5/31/91
TIME OF TEST : 9:45

TEST DESCRIPTION : 50 FT BY 50 FT POOL FIRE

WIND SPEED : 1 m / sec
WIND DIRECTION : 110 degrees

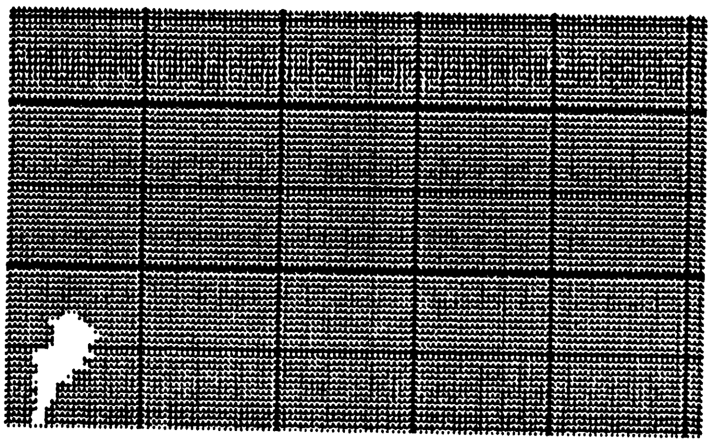
FRONT VIEW CAMERA DIRECTION : 240 degrees
FRONT VIEW CAMERA DISTANCE : 3500 m
SIDE VIEW CAMERA DIRECTION : 42 degrees
SIDE VIEW CAMERA DISTANCE : 650 m

TEST LENGTH : 600 seconds
TIME STEP : 120 seconds

TEST NUMBER : 8
ELAPSED TIME : 02:00

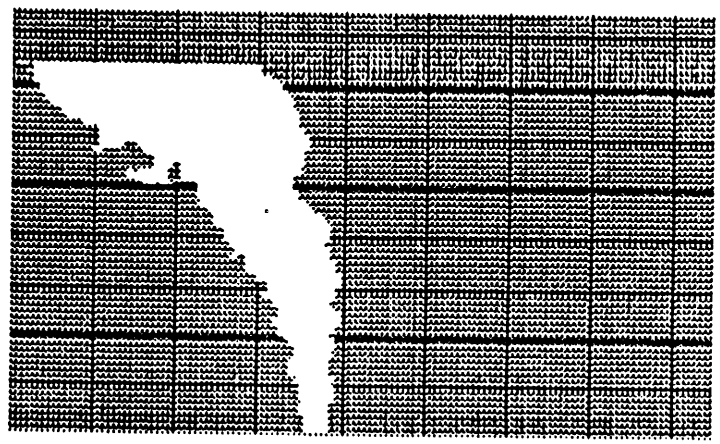
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	740	625	METERS
MAX. DISTANCE :	297	157	METERS
VOLUME OF SMOKE :	8527819	5890826	CU. METERS
PRODUCTION RATE :	4263909	2945413	CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 100 m



CAMERA #2

FLUME TRAJECTORY

TEST NUMBER 8
ELAPSED TIME 02:00

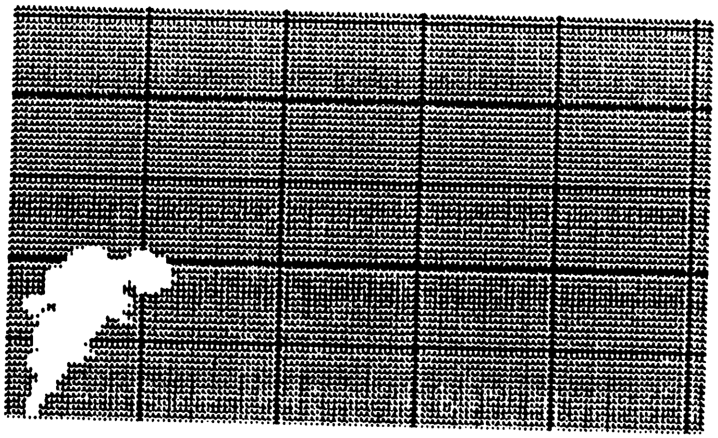
COMPASS HEADING 290 degrees

DISTANCE (M)	HEIGHT (M)
0	0
14	73
29	147
43	220
57	294
72	367
86	441
100	478
115	515
129	551
143	588
158	625

TEST NUMBER : 8
ELAPSED TIME : 04:00

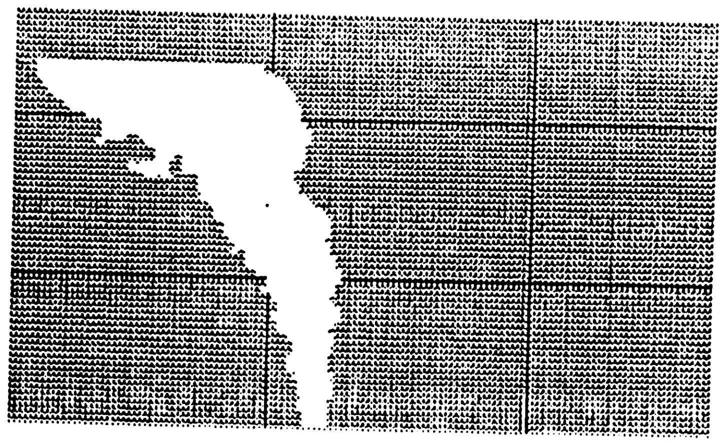
	TWO VIEW APPROACH	CENTER LINE APPROACH
MAX. HEIGHT :	1180	1006 METERS
MAX. DISTANCE :	480	301 METERS
VOLUME OF SMOKE :	4.620254E+07	4.482372E+07CU. METERS
PRODUCTION RATE :	1.883736E+07	1.946644E+07CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 500 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 8
ELAPSED TIME 04:00

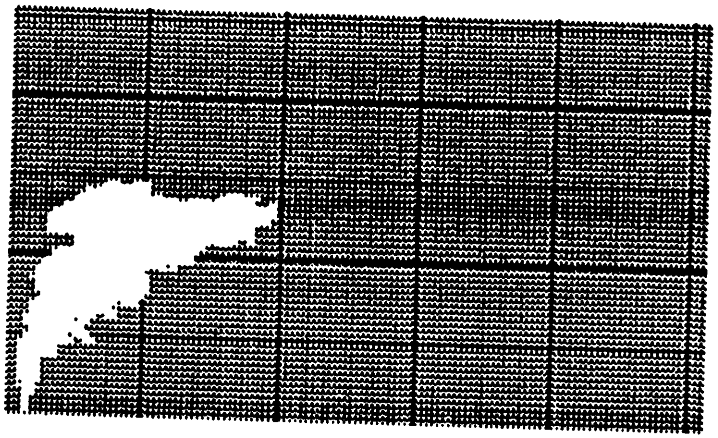
COMPASS HEADING 290 degrees

DISTANCE (M)	HEIGHT (M)
0	0
14	67
29	133
43	200
57	267
72	334
86	401
122	501
158	602
194	703
229	804
265	905
301	1006

TEST NUMBER : 8
ELAPSED TIME : 06:00

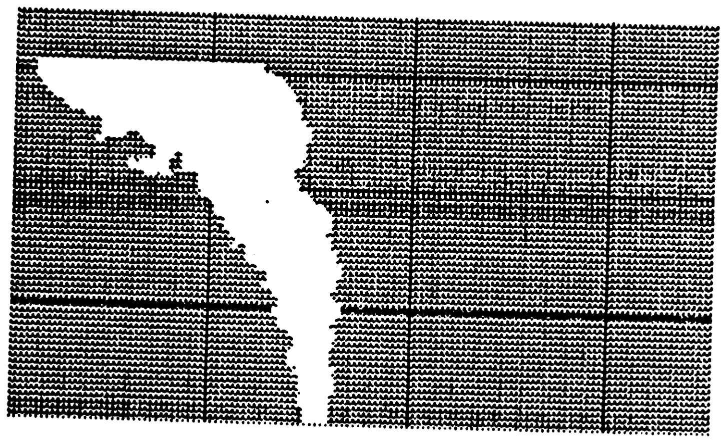
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	1540	1395	METERS
MAX. DISTANCE :	820	537	METERS
VOLUME OF SMOKE :	1.394121E+08	1.709878E+08	CU. METERS
PRODUCTION RATE :	4.660479E+07	6.308206E+07	CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 500 m



CAMERA #2

FLUME TRAJECTORY

TEST NUMBER 8
ELAPSED TIME 06:00

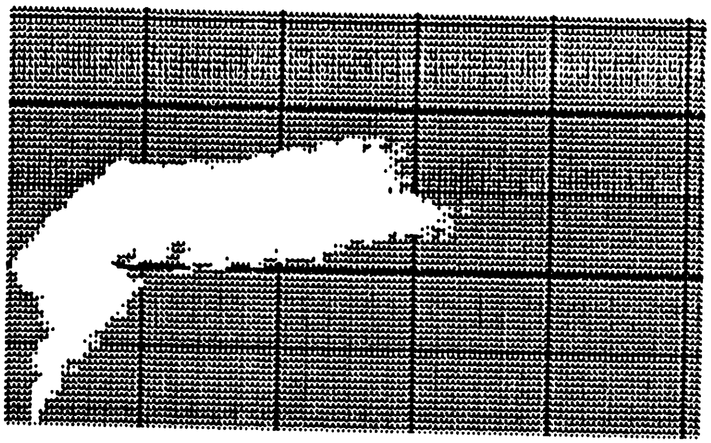
COMPASS HEADING 290 degrees

DISTANCE (M)	HEIGHT (M)
0	0
14	87
29	173
43	260
57	347
72	434
86	521
115	575
143	629
172	682
201	736
229	790
258	845
305	936
351	1028
398	1119
444	1211
491	1303
538	1396

TEST NUMBER : 8
ELAPSED TIME : 08:00

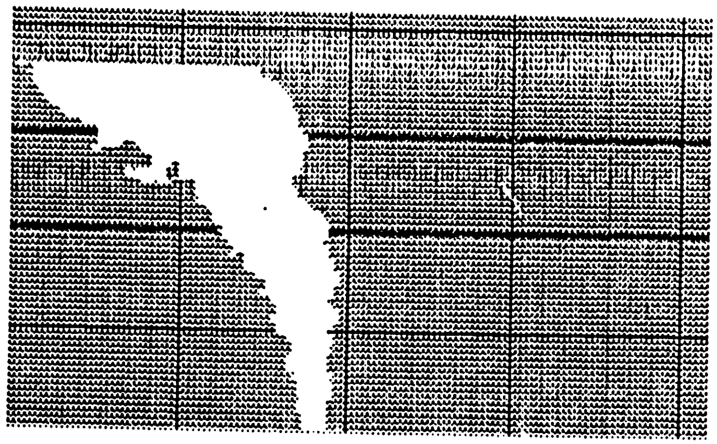
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	1820	1573	METERS
MAX. DISTANCE :	1480	1261	METERS
VOLUME OF SMOKE :	3.448601E+08	4.858529E+08	CU. METERS
PRODUCTION RATE :	1.02724E+08	1.574325E+08	CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 500 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 8
ELAPSED TIME 08:00

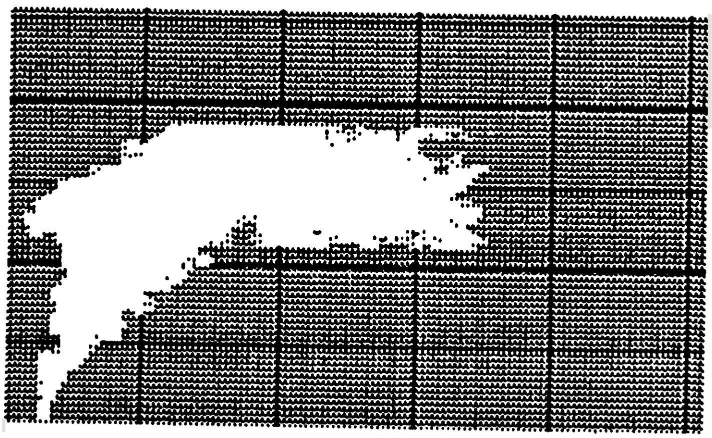
COMPASS HEADING 290 degrees

DISTANCE (M)	HEIGHT (M)
0	0
29	107
57	214
86	321
115	428
143	535
172	642
186	736
201	830
215	924
229	1018
244	1112
258	1206
459	1279
659	1352
860	1425
1061	1499
1262	1574

TEST NUMBER : 8
ELAPSED TIME : 10:00

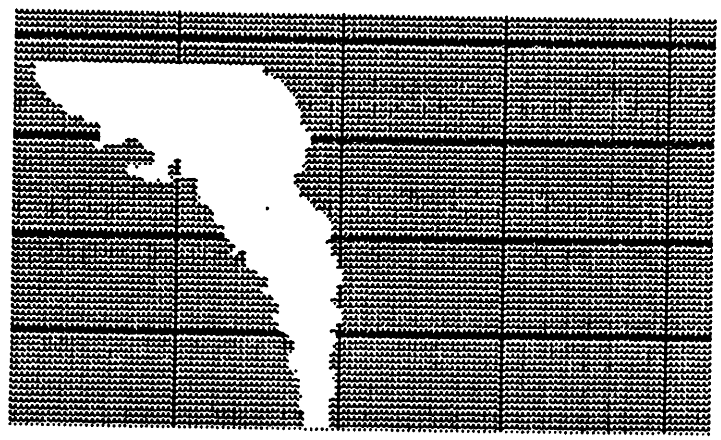
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	1860	1645	METERS
MAX. DISTANCE :	1660	1562	METERS
VOLUME OF SMOKE :	4.597073E+08	5.181033E+08	CU. METERS
PRODUCTION RATE :	5.742358E+07	1.612518E+07	CU. METERS PER MINUTE

LINES = 500 m



CAMERA #1

LINES = 500 m



CAMERA #2

FLUME TRAJECTORY

TEST NUMBER 8
ELAPSED TIME 10:00

COMPASS HEADING 290 dearees

DISTANCE (M)	HEIGHT (M)
0	0
7	57
14	113
22	170
29	227
36	284
43	340
72	421
100	501
129	582
158	662
186	74a
215	824
215	824
272	932
330	1040
387	1149
444	1258
502	1368
559	1477
760	1510
960	1544
1161	1578
1362	1611
156s	1646

Appendix C
Program Listings

```
1 DEFINT A,C,O
2 DIM AS(80,120),AF(60,100),WF(200),WS(200),V(2,10)
3 DIM CROSS(2,2),POLY(50,2),TR(200,2)
4 DIM YMIN(50),YMAX(50),SLOPE(50),YINT(50)
6 DIM CR(500),O(500)
8 SCREEN 9:KEY OFF:CLS:GET (0,0)-(10,10),O:COLOR 4:LOCATE 1,1:PRINT "*":GET (0,0
20   QE = 10
30 P%=0 :I%=0:J%=0:DIM ARRAY%(3)
40 DATA &H55                    :' PUSH BP
50 DATA &HCD, &H05              :' CD05 INT 5
60 DATA &H5D                    :' 5DH POP BP
70 DATA &HCB                    :' CBH RET FAR
80                              :' 90H NOP
90 P%=VARPTR(ARRAY%(1)):FOR I%=0 TO 4:READ J%:POKE(P%+I%),J%:NEXT I%
95 SCREEN 0:CLS:LOCATE 5,5:INPUT" ENTER TEST NUMBER "; NUM
99 FILE$="INDAT"+RIGHT$(STR$(1000+NUM),3)+".DAT"
100 ' *****  INPUT INITIAL INFORMATION *********
120 OPEN FILE$ FOR INPUT AS #1
200 LINE INPUT #1, A$
201 LINE INPUT #1, B$
202 LINE INPUT #1, C$
203 LINE INPUT #1, D$
204 LINE INPUT #1, E$
205 LINE INPUT #1, F$
206 LINE INPUT #1, G$
207 LINE INPUT #1, H$
208 LINE INPUT #1, I$
209 LINE INPUT #1, J$
210 LINE INPUT #1, K$
211 LINE INPUT #1, L$
300 CLOSE #1
400 ' ***** CONVERT TO NUMBERS ******
410 WSPEED=VAL(D$)
420 WDIR=VAL(E$)
430 FCAMDIR=VAL(F$)
440 FCAMDIS=VAL(G$)
450 SCAMDIR=VAL(H$)
460 SCAMDIS=VAL(I$)
470 TESTLEN=VAL(J$)
480 INC=VAL(K$)
490 LHARDCOPY=VAL(L$)
495 SHARDCOPY=VAL(M$)
500 ' *****  DISPLAY INFORMATION  *******
505 GOSUB 550
507 SCREEN' 9
510 COLOR 15:LOCATE 1,20:PRINT " VISIBLE SMOKE PLUME CALCULATOR"
511 COLOR 7:LOCATE 3,5:PRINT " TEST NUMBER : ";NUM
512 COLOR 7:LOCATE 4,5:PRINT " DATE OF TEST : ";A$
513 COLOR 7:LOCATE 5,5:PRINT " TIME OF TEST : ";B$
514 COLOR 7:LOCATE 7,5:PRINT " TEST DESCRIPTION : ";C$
515 COLOR 7:LOCATE 9,5:PRINT " WIND SPEED : ";D$;" m / sec"
516 COLOR 7:LOCATE 10,5:PRINT " WIND DIRECTION : ";E$;" degrees"
517 COLOR 7:LOCATE 12,5:PRINT " FRONT VIEW CAMERA DIRECTION : ";F$;" degrees"
518 COLOR 7:LOCATE 13,5:PRINT " FRONT VIEW CAMERA DISTANCE : ";G$;" m"
519 COLOR 7:LOCATE 14,5:PRINT " SIDE VIEW CAMERA DIRECTION : ";H$;" degrees"
520 COLOR 7:LOCATE 15,5:PRINT " SIDE VIEW CAMERA DISTANCE : ";I$;" m"
521 COLOR 7:LOCATE 17,5:PRINT " TEST LENGTH : ";J$;" seconds"
522 COLOR 7:LOCATE 18,5:PRINT " TIME STEP : ";K$;" seconds"
523 COLOR 9:LOCATE 22,5:PRINT " CHECK ALL OF THE ABOVE INFORMATION"
524 COLOR 9:LOCATE 23,5:PRINT " PRESS C TO CONTINUE OR E TO EXIT PROGRAM"
525 COLOR 15
526 R$=INKEY$
527 IF R$="c" OR R$="C" THEN GOTO 600
528 IF R$="e" OR R$="E" THEN SYSTEM
530 GOTO 526
550 ' ***** OUTPUT TO A DATA FILE *****
```

```
551 FILE$="SUM"+RIGHT$(STR$(1000+NUM),3)+".DAT"
552 OPEN FILE$ FOR OUTPUT AS #2
553 PRINT #2,
554 PRINT #2," VISIBLE SMOKE PLUME CALCULATOR"
555 PRINT #2," DATE OF TEST : ";A$
556 PRINT #2," TIME OF TEST : ";B$
557 PRINT #2," TEST DESCRIPTION : ";C$
558 PRINT #2," WIND SPEED : ";D$;" m / sec"
559 PRINT #2," WIND DIRECTION : ";E$;" degrees"
560 PRINT #2," FRONT VIEW CAMERA DIRECTION : ";F$ ;" degrees"
561 PRINT #2," FRONT VIEW CAMERA DISTANCE : ";G$;" m"
562 PRINT #2," SIDE VIEW CAMERA DIRECTION : ";H$;" degrees"
563 PRINT #2," SIDE VIEW CAMERA DISTANCE : "; I$;" m"
564 PRINT #2," TEST LENGTH : ";J$;" seconds"
565 PRINT #2," TIME STEP : ";K$;" seconds"
566 PRINT #2,
567 PRINT #2,
568 RETURN
600 CLS
700 IF VAL(E$)>180 THEN N$=STR$(VAL(E$)-180):GOTO 10C
800 N$=STR$(VAL(E$)+180)
1000 FOR C=INC TO TESTLEN STEP INC
1020 GOSUB 10000
1030 GOSUB 50000
1035 IF LHARDCOPY=1 AND TITLEPAGE=0 THEN GOSUB 1500
1040 GOSUB 26000
1045 GOSUB 30000
1050 NEXT C
1055 CLOSE #2
1060 GOTO 95
1500 ' *****  PRINTOUT INITDATA   *******
1510 SCREEN 9:CLS:TITLEPAGE=1
1511 COLOR 15:LOCATE 1,20:PRINT " VISIBLE SMOKE PLUME CALCULATOR"
1512 COLOR 7:IDCATE 4,5:PRINT " DATE OF TEST : ";A$
1513 COLOR 7:LOCATE 5,5 :PRINT " TIME OF TEST : ";B$
1514 COLOR 7:LOCATE 7,5 :PRINT " TEST DESCRIPTION : ";C$
1515 COLOR 7:LOCATE 9,5 :PRINT " WIND SPEED : ";D$;" m / sec"
1516 COLOR 7:LOCATE 10,5 :PRINT " WIND DIRECTION : ";E$;" degrees"
1517 COLOR 7:LOCATE 12,5:PRINT " FRONT VIEW CAMERA DIRECTION : ";F$;" degrees"
1518 COLOR 7:LOCATE 13,5 :PRINT " FRONT VIEW CAMERA DISTANCE : ";G$;" m"
1519 COLOR 7:LOCATE 14,5 :PRINT " SIDE VIEW CAMERA DIRECTION : ";H$;" degrees"
1520 COLOR 7:LOCATE 15,S:PRINT " SIDE VIEW CAMERA DISTANCE : ";I$;" m"
1521 COLOR 7:LOCATE 17,5:PRINT " TEST LENGTH : ";J$;" seconds"
1522 COLOR 7:LOCATE 18,5 :PRINT " TIME STEP : ";K$;" seconds"
1524 LPRINT CHR$(12)
1526 DEF USRO = VARPTR(ARRAY%(1)): Y=USRO(X)
1528 RETURN
10000 '******   INPUT FRONT v DATA   ********
10005 SCREEN 9:CLS:COLOR 4:LOCATE 13,30 :PRINT "RETRIEVING DATA"
10010 FOR I=1 TO 60:FOR J=1 TO 100:AF(I,J)=0·NEXT J:NEXT I:TR=0
10020 FILEA$ = "F"+ RIGHT$(STR$(1000+NUM),3) + RIGHT$(STR$(10000+C), 4) + ".DAT"
10600 OPEN FILEA$ FOR INPUT AS #1
10800 INPUT #1,FSCALE,FCOL,FROW
11000 FOR ROW = 1 TO FROW
11200 FOR COL = 1 TO FCOL
11400 INPUT #1,AF(COL,ROW)
11410 W=W+AF(COL,ROW)
11600 NEXT COL
11610 WF(ROW)=W*FSCALE:W=0
11800 NEXT ROW
12000 CLOSE #1
13000 'RETURN
20000 '******   INPUT SIDE v DATA  ********
20010 FOR I=1 TO 80:FOR J=1 TO 120:AS(I,J)=0:NEXT J:NEXT I
20020 FILEA$ = "S" + RIGHT$(STR$(1000+NUM),3) + RIGHT$(STR$(10000+C), 4) + ".DAT
20130 IF C < 10 THEN FILEA$ = "S" + RIGHT$(STR$(C), 1) + ".DAT"
```

```
20600 OPEN FILEA$ FOR INPUT AS #1
20800 INPUT #1,SSCALE,SCOL,SROW
20900 SSCALE=FROW/SROW*FSCALE
21000 FOR ROW = 1 TO SROW
21200 FOR COL = 1 TO SCOL
21400 INPUT #1,AS(COL,ROW)
21410 W=W+AS(COL,ROW)
21600 NEXT COL
21610 WS(ROW)=W*SSCALE:W=0
21800 NEXT ROW
22000 CLOSE #1
22010 CLS:COLOR 15
23000 RETURN
24000 '*****  SHOW VIEWS ON SCREEN TO SCALE *****
24010 LINE(25,200)-(275,300),3,BF
24020 FOR ROW = 1 TO FROW
24030 FOR COL = 1 TO FCOL
24040 IF AF(COL,ROW)=0 THEN GOTO 24060
24050 LINE(25+(COL*2-2)*FSCALE/30-FSCALE/30,300-ROW*FSCALE/30-FSCALE/30)-(25+(CO
24060 NEXT COL
24070 NEXT ROW
25000 '*****  SHOW VIEWS ON SCREEN TO SCALE *****
25010 LINE(300,200)-(550,300),3,BF
25020 FOR ROW = 1 TO SROW
25030 FOR COL = 1 TO SCOL
25040 IF AS(COL,ROW)=0 THEN GOTO 25060
25050 LINE(300+(COL*2-2)*SSCALE/30-SSCALE/30,300-ROW*SSCALE/30-SSCALE/30)-(300+(
25060 NEXT COL
25070 NEXT ROW
26000 '*****  SHOW VIEWS ON SCREEN TO SCALE *****
26001 IF FSCALE >= SSCALE THEN MD=FSCALE*128 ELSE MD=SSCALE*128
26002 DFSCALE=FSCALE/(MD/128):DSSCALE=SSCALE/(MD/128)
26004 IF MD>1000 THEN SPACING=500 ELSE SPACING=100
26005 CLS:COLOR 15
26010 LINE(25,172)-(281,300),3,BF
26100 ' *** ADD SCALING LINES ***
26110 FOR I=SPACING TO MD STEP SPACING
26120 SF=CINT(I/(MD/128))
26200 ' *** X SCALING LINES ***
26210 'IF SF>FCOL*SCALE THEN GOTO 26300
26220 LINE(25+SF*2,300)-(25+SF*2,172),15
26300 ' *** Y SCALING LINES ***
26310 'IF SF>FROW*SCALE THEN GOTO 26300
26350 LINE(25,300-SF)-(281,300-SF),15
26400 NEXT I
26520 FOR ROW = 1 TO FROW
26530 FOR COL = 1 TO FCOL
26540 IF AF(COL,ROW)=0 THEN GOTO 26560
26545 NCOL=COL*DFSCALE:NROW=ROW*DFSCALE
26550 LINE(25+NCOL*2-2,300-NROW)-(25+NCOL*2,300-NROW),0,BF
26560 NEXT COL
26570 NEXT ROW
26580 LOCATE 23,15:PRINT "CAMERA #1"
26590 LOCATE 12,12:PRINT "LINES = ";SPACING;" m"
27000 '*****  SHOW VIEWS ON SCREEN TO SCALE *****
27010 LINE(300,172)-(556,300),3,BF
27100 ' *** ADD SCALING LINES ***
27110 FOR I=SPACING TO MD STEP SPACING
27120 SF=CINT(I/(MD/128))
27200 ' *** X SCALING LINES ***
27210 'IF SF>SCOL*SSCALE THEN GOTO 27300
27220 LINE(300+SF*2,300)-(300+SF*2,172),15
27300 ' *** Y SCALING LINES ***
27310 'IF SF>SROW*SSCALE THEN GOTO 27300
27350 LINE(300,300-SF)-(556,300-SF),15
27400 NEXT I
```

```
27520 FOR ROW = 1 TO SROW
27530 FOR COL = 1 TO SCOL
27540 IF AS(COL,ROW)=0 THEN GOTO 27560
27545 NCOL=COL*DSSCALE:NROW=ROW*DSSCALE
27550 LINE(300+NCOL*2-2,300-NROW)-(300+NCOL*2,300-NROW),0,BF
27560 NEXT COL
27570 NEXT ROW
27580 LOCATE 23,50:PRINT "CAMERA #2"
27590 LOCATE 12,46:PRINT "LINES = ";SPACING;" m"
28500 RETURN
30000 ' ****** VOLUME CALCULATION *******
30001 IF FROW*FSCALE > SROW*SSCALE THEN MH=FROW*FSCALE ELSE MH=SROW*SSCALE
30005 V=0:DIS=0:MAX=0
30010 FOR H=0 TO MH STEP 10
30012 HF=CINT(H/FSCALE):HS=CINT(H/SSCALE)
30013 IF WF(HF)=0 AND WS(HS)=0 THEN GOTO 30030
30014 MAX1=H
30017 IF WF(HF)=0 AND WS(HS)<>0 THEN WF(HF)=WF(HF-1)
30018 IF WS(HS)=0 AND WF(HF)<>0 THEN WS(HS)=WS(HS-1)
30019 IF WF(HF)>DIS1 THEN DIS1=WF(HF)
30020 IF WS(HS)>DIS1 THEN DIS1=WS(HS)
30022 V=V+(3.14*WF(HF)*WS(HS))*10/4
30030 NEXT H
30035 V(1,C\INC)=V
30037 T$=RIGHT$(STR$(100+C\60),2)+":"+RIGHT$(STR$(100+ C MOD 60),2)
30038 LOCATE 1,5:PRINT "TEST NUMBER ";NUM
30040 LOCATE 2,5:PRINT "ELAPSED TIME ";T$
30042 LOCATE 3,20:PRINT "TWO VIEW APPROACH   CENTER LINE APPROACH"
30044 LOCATE 5,5:PRINT "MAX. HEIGHT :"
30046 LOCATE 5,25:PRINT  INT(MAX1)
30048 LOCATE 5,45:PRINT  INT(MAX2)
30050 LOCATE 5,58:PRINT "METERS"
30052 LOCATE 6,5:PRINT "MAX. DISTANCE :"
30054 IDCATE 6,25:PRINT INT(DIS1)
30056 LOCATE 6,45:PRINT INT(DIS2)
30058 LOCATE 6,58:PRINT "METERS"
30060 LOCATE 7,5:PRINT VOLUME OF SMOKE :"
30062 IDCATE 7,25:PRINT  INT(V(1,C\INC))
30064 IDCATE 7,45:PRINT INT(V(2,C\INC))
30066 LOCATE 7,58:PRINT "CU. METERS"
30068 LOCATE 8,5:PRINT "PRODUCTION RATE :"
30070 LOCATE 8,25:PRINT INT((V(1,C\INC)-V(1,C\INC-1))*60/INC)
30072 LOCATE 8,45:PRINT INT((V(2,C\INC)-V(2,C\INC-1))*60/INC)
30074 LOCATE 8,58:PRINT "CU. METERS PER MINUTE"
30076 PRINT #2,
30078 PRINT #2,
30079 PRINT #2,"TEST NUMBER ";NUM
30080 PRINT #2,"TIME ";T$
30082 PRINT #2,"TWO VIEW APPROACH   CENTER LINE APPROACH"
30084 PRINT #2,"MAX. HEIGHT :  ";INT(MAX1);"     ";INT(MAX2);"   METERS"
30086 PRINT #2,"MAX. DISTANCE :   ";INT(DIS1);"     ";INT(DIS2);"   METERS"
30088 PRINT #2,"VOLUME OF SMOKE :   "INT(V(1,C\INC));"     ";INT(V(2,C\INC));"
30090 PRINT #2,"PRODUCTION RATE :   " INT((V(1,C\INC)-V(1,C\INC-1))*60/INC);"
30092 PRINT #2,
30094 PRINT #2,
30098 IF LHARDCOPY=1 THEN GOTO 30130
30100 R$=INKEY$
30110 IF R$="c" OR R$="C" THEN GOTO 31000
30120 GOTO 30100
30130 LPRINT CHR$(12)
30140 DEF USRO = VARPTR(ARRAY%(1)): Y=USRO(X)
31000 '**** TRAJECTORY ******
31010 CLS
31020 PRINT "                PLUME TRAJECTORY    "
31022 PRINT
31023 PRINT "     TEST NUMBER ";NUM
```

```
31024 PRINT "     ELAPSED TIME ";T$
31025 PRINT
31026 PRINT "     COMPASS HEADING ";N$;" degrees"
31028 PRINT
31030 PRINT "     DISTANCE (M)           HEIGHT (M)"
31032 PRINT
31120 PRINT #2, "                 PLUME TRAJECTORY    "
31122 PRINT #2,
31123 PRINT #2,
31124 PRINT #2, "     TEST NUMBER ";NUM
31125 PRINT #2, "     ELAPSED TIME ";T$
31126 PRINT #2, "     COMPASS HEADING ";N$;" degrees"
31128 PRINT #2,
31130 PRINT #2, "     DISTANCE (H)           HEIGHT (M)"
31132 PRINT #2,
31140 FOR I=1 TO TR
31150 PRINT USING "        #####           ";TR(I,1);TR(I,2)
31152 PRINT #2,USING"       #####           ";TR(I,1);TR(I,2)
31160 NEXT I
32000 ' ****** TRAJECTORY PRINTOUT *****
32010 IF LHARDCOPY=0 THEN GOTO 32200
32030 LPRINT CHR$(12)
32040 LPRINT "                 PLUME TRAJECTORY    "
32041 LPRINT
32042 LPRINT "     TEST NUMBER ";NUM
32043 LPRINT "     ELAPSED TIME ";T$
32044 LPRINT
32046 LPRINT "     COMPASS HEADING ";N$;" degrees"
32048 LPRINT
32050 LPRINT "     DISTANCE (M)           HEIGHT (M)"
32052 LPRINT
32060 FOR I=1 TO TR
32070 LPRINT USING "        #####           ";TR(I,1);TR(I,2)
32080 NEXT I
32170 R$=INKEY$
32180 IF R$="c" OR R$="C" THEN GOTO 32200
32190 GOTO 32170
32200 RETURN
50000 ' *********  DRAW  **********
50001 FOR I=1 TO 50:SLOPE(I)=0:YMIN(I)=0:YMAX(I)=0:YINT(I)=0:POLY(I,1)=0:POLY(I,
50010 RADMIN=10000:RADMAX=0:XO=0:YO=0
50020 CROSS(1,1)=40:CROSS(1,2)=240
50030 CROSS(2,1)=40:CROSS(2,2)=240
50040 GOSUB 50560
50042 FOR B = 1 TO 640 STEP 16: LINE (1, 260)-(B, 349), 0, BF: NEXT B
50044 COIDR 2:LOCATE 22,18:PRINT "CALCULATING THE VOLUME OF THE PLUME"
50050 FOR N=1 TO POLY
50060 'PRINT POLY(N,1),POLY(N,2)
50070 NEXT N
50080 FOR N=1 TO POLY-2
50090 'PRINT POLY(N,1),POLY(N,2),POLY(N+1,1),POLY(N+1,2)
50100 IF (POLY(N+1,1)-POLY(N,1))=0 THEN POLY(N+1,1)=POLY(N,1)+1
50110 IF (POLY(N+1,2)-POLY(N,2))=0 THEN POLY(N+1,2)=POLY(N,2)+1
50120 IF POLY(N,2)<POLY(N+1,2) THEN YMIN(N)=POLY(N,2) ELSE YMIN(N)=POLY(N+1,2)
50130 IF POLY(N,2)>POLY(N+1,2) THEN YMAX(N)=POLY(N,2) ELSE YMAX(N)=POLY(N+1,2)
50140 SLOPE(N)=(POLY(N+1,2)-POLY(N,2))/(POLY(N+1,1)-POLY(N,1))
50150 YINT(N)=POLY(N,2)-SLOPE(N)*POLY(N,1)
50160 'PRINT YMIN(N),YMAX(N),SLOPE(N),YINT(N)
50170 NEXT N
50175 V=0
50180 FOR N=1 TO POLY-2
50185 RAD=0:RADSUM=0
50190 FOR Y=YMAX(N) TO YMIN(N) STEP ((YMIN(N)-YMAX(N))/6)
50195 PSET((Y-YINT(N))/SLOPE(N),Y),2
50200 X=(Y-YINT(N))/SLOPE(N)
50201 NSLOPE=1/((-SLOPE(N))*2)
```

```
50202 YINT=Y-NSLOPE*X
50203 GOSUB 50530 'TRAGECTORY
50204 P1X=X:P2X=X:P1Y=Y:P2Y=Y
50205 GOSUB 50250 'RADIUS LINES
50206 LINE(P1X,P1Y)-(P2X,P2Y),2
50207 GOSUB 50500
50210 NEXT Y
50215 GOSUB 50400
50220 NEXT N
50225 V(2,C\INC)=V
50230 RETURN
50240 '
50250 ' ***** RADIUS SUBROUTINE  *****
50255 P1=0:P2=0
50257 IF NSLOPE<-20 OR NSLOPE>20 THEN S=.1 ELSE S=1
50260 FOR NX=64 TO FCOL*4+68 STEP S
50270 NY=NX*NSLOPE+YINT':PSET(NX,NY),2
50275 COL=CINT((NX-64)/4):ROW=CINT((259-NY)/2)':PRINT COL,ROW
50276 IF COL<1 OR COL>1+FCOL THEN GOTO 50300
50278 IF ROW<1 OR ROW>1+FROW THEN GOTO 50300
50280 IF AF(COL,ROW)=1 AND P1=0 THEN GOTO 50320
50290 IF AF(COL,ROW)=0 AND P1=1 AND P2=0 THEN GOTO 50350
50295 IF P1=1 AND P2=1 THEN GOTO 50310
50300 NEXT NX
50310 RETURN
50320 ' ****** FIRST POINT ****
50330 P1X=NX:P1Y=NY:P1=1
50340 GOTO 50300
50350 ' ****** SECOND POINT ****
50360 P2X=NX:P2Y=NY:P2=1
50365 IF P2X<X-10 THEN P2=0
50370 GOTO 50300
50380 '
50390 '
50400 '  *****  CENTER LINE VOLUME CALCULATION *****
50410 '
50415 '
50420 LDX=ABS((POLY(N+1,1)-POLY(N,1))/SIN(VAL(E$)-VAL(F$)))
50425 DD=((LDX)^2-(POLY(N+1,1)-POLY(N,1))^2)^.5
50430 LDY=ABS(POLY(N+1,2)-POLY(N,2))*((VAL(G$)+DD)/VAL(G$))
50435 L=((LDX^2+(LDY*2)^2)^.5)*FSCALE/4
50445 RADAVG=((RADSUM-RADMIN-RADMAX)/5)*FSCALE/4
50450 V=V+3.14*RADAVG^2*L
50455 'PRINT V
50460 RETURN
50500 '  *****  RADIUS CALCULATION RUNNING SUM  *****
50501 RDX=ABS((P1X-P2X)/SIN(VAL(E$)-VAL(F$)))
50502 DD=((RDX)^2-(P1X-P2X)^2)^.5
50503 RDY=ABS(P1Y-P2Y)*((VAL(G$)+DD)/VAL(G$))
50504 RAD=((RDX^2+(RDY*2)^2)^.5)/2
50505 RADSUM=RADSUM+RAD
50506 IF RAD<RADMIN THEN RADMIN=RAD
50507 IF RAD>RADMAX THEN RADMAX=RAD
50508 RETURN
50530 ' ***** TRAJECTORY *****
50531 TR=TR+1
50532 IF XO=0 THEN XO=X
50533 IF YO=0 THEN YO=Y
50534 TRX=ABS((X-XO)/SIN(VAL(E$)-VAL(F$)))
50535 TDD=((TRX)^2-(X-XO)^2)^.5
50536 TRY=ABS(Y-YO)*((VAL(G$)+TDD)/VAL(G$))
50537 TR(TR,1)=TRX*FSCALE/4
50538 TR(TR,2)=TRY*FSCALE/2
50539 DIS2=TR(TR,1)
50540 MAX2=TR(TR,2)
50541 RETURN
```

```
50560 ' *******  DRAW PLUME  *********
50570 SCREEN 9:KEY OFF:CLS
50580 FINISHED=0 :POLY=0
50585 GOSUB 51000
50590 POLY=POLY+1
50600 GOSUB 50722
50610 IF FINISHED31 THEN RETURN
50620 POLY(POLY,1)=CROSS(1,1)
50630 POLY(POLY,2)=CROSS(1,2)
50680 GOTO 50590
50720 'GOSUB 51000
50722 LOCATE 20,20:PRINT "DRAW THE CENTER LINE OF THE PLUME"
50724 LOCATE 21,25:PRINT "PRESS P TO SET A POINT"
50726 LOCATE 22,15:PRINT "PRESS C WHEN COMPLETE OR R TO REDO CENTER LINE"
50730 PUT (CROSS(1,1)-15,CROSS(1,2)-15),O,AND
50740 GET(CROSS(2,1)-15,CROSS(2,2)-15)-(CROSS(2,1)+15,CROSS(2,2)+15),O
50750 PUT(CROSS(2,1)-3,CROSS(2,2)-5),CR
50754 FOR POL=2 TO POLY-1
50758 IF POLY>2 THEN LINE(POLY(POL-1,1),POLY(POL-1,2))-(POLY(POL,1),POLY(POL,2))
50760 NEXT POL
50770 CROSS(1,1)=CROSS(2,1)
50780 CROSS(1,2)=CROSS(2,2)
50790 R$=INKEY$
50800 IF R$=CHR$(0)+"M" AND CROSS(2,1)<572 THEN CROSS(2,1)=CROSS(1,1)+4 :GOTO 507
50810 IF R$=CHR$(0)+"K" AND CROSS(2,1)>69 THEN CROSS(2,1)=CROSS(1,1)-4:GOTO 5073
50820 IF R$=CHR$(0)+"P" AND CROSS(2,2)<256 THEN CROSS(2,2)=CROSS(1,2)+2:GOTO 507
50830 IF R$=CHR$(0)+"H" AND CROSS(2,2)>4 THEN CROSS(2,2)=CROSS(1,2)-2 :GOTO 50730
50840 IF R$="6" AND CROSS(2,1)<561 THEN CROSS(2,1)=CROSS(1,1)+16:GOTO 50730
50850 IF R$="4" AND CROSS(2,1)>80 THEN CROSS(2,1)=CROSS(1,1)-16:GOTO 50730
50860 IF R$="2" AND CROSS(2,2)<250 THEN CROSS(2,2)=CROSS(1,2)+8:GOTO 50730
50870 IF R$="8" AND CROSS(2,2)>9 THEN CROSS(2,2)=CROSS(1,2)-8:GOTO 50730
50880 IF R$="P" OR R$="p" THEN RETURN
50885 IF R$="R" OR R$="r" THEN GOTO 50560
50890 IF R$="C" OR R$="c" THEN FINISHED=1:RETURN
50900 GOTO 50770
51000 ' *****  LARGE VIEW  *****
51010 'LINE(64,1)-(578,259),7,B
51020 FOR ROW = 1 TO FROW
51030 FOR COL = 1 TO FCOL
51040 IF AF(COL,ROW)=0 THEN GOTO 51060
51050 LINE(64+COL*4-3,259-ROW*2-2)-(64+COL*4,259-ROW*2),8,BF
51060 NEXT COL
51070 NEXT ROW
51080 RETURN
```

```
1 DEFINT A-R, T-Z
2 DIM CROSS(2, 2)
3 DIM W(512), ADJUST(1000), VALUE(512)
4 DIM POLY(25, 2)
5 DIM YMIN(50), YMAX(50), SLOPE(50), YINT(50), LIN(10), EDGE(10)
6 DIM D(128, 128)
10 DECLARE FUNCTION AUINXT CDECL
20 DECLARE FUNCTION AUSYNC CDECL (BYVAL N AS INTEGER)
30 DECLARE FUNCTION AUDISP CDECL (BYVAL N AS INTEGER)
40 DECLARE FUNCTION AUSETOVL CDECL ALIAS "au_set_ovl_plns" (BYVAL N AS INTEGER)
50 DECLARE FUNCTION AUEND CDECL ALIAS "au_end"
60 DECLARE FUNCTION AUPASS CDECL
70 DECLARE FUNCTION AUFREZ CDECL
80 DECLARE FUNCTION AUGTPX CDECL (BYVAL BN AS INTEGER, BYVAL RN AS INTEGER, BWA
90 DECLARE FUNCTION AUPTPX CDECL (BYVAL BN AS INTEGER, BYVAL RN AS INTEGER, BYVA
100 DECLARE FUNCTION AUSOVP CDECL (SEG N%)
105 DECLARE FUNCTION AULINE CDECL (BYVAL PC AS INTEGER,SEG N%,BYVAL MODE AS INTE
108 DECIARE FUNCTION AUGPOS CDECL (BYVAL ROW AS INTEGER,BYVAL COL AS INTEGER,BYV
109 DECLARE FUNCTION AUBOX CDECL (BYVAL HT AS INTEGER,BYVAL WD AS INTEGER,BYVAL
110 'Buffer 0 = Intensity
120 '       1 = Saturation
130 '       2 = Hue
140 '       3 = Overlay
150 '
160 DECLARE FUNCTION AUBCLR CDECL (BYVAL N AS INTEGER)
200 GOTO 1000
475 ' *******  CAPTURE FRAME *******
480 01 = 0
490 02 = 0
500 03 = 1              'Enable bit plane 2  (Write value = 64)
510 04 = 1              'Enable bit plane 1  (Write valu2 = 128)
520 X = AUINIT
530 X = AUBCLR(0)
540 X = AUBCLR(3)
550 X = AUSYNC(1)
560 X = AUPASS
580 X = AUSOVP(O1)
590 X = AUFREZ
600 RETURN
700  ' *****  REQUEST BIT STATUS  ******
705 ' ROW  & COL = 0 TO  511  Z IS THE RETURNED VALUE 1-256
710 X = AUGTPX(0, ROW, COL, 1, Z)
720 RETURN
800 ' ******  ADD A POINT ON TV SCREEN  *****
810 ' ******  y = 128 -> crosshair point   y = 64 -> plume point ******
820 X = AUGTPX(3, ROW, COL, 1, Y1)
822 Y = Y OR Y1
825 X = AUPTPX(3, ROW, COL, 1, Y)
828 X = AUPTPX(3, ROW - 1, COL, 1, Y)
830 RETURN
850 ' ******  REMOVE A POINT FROM SCREEN  *****
860 ' ******  y = 127 -> crosshair point   y = 191 -> plume point
870 X = AUGTPX(3, ROW, COL, 1, Y1)
880 Y = Y AND Y1
883 X = AUPTPX(3, ROW, COL, 1, Y)
885 X = AUPTPX(3, ROW - 1, COL, 1, Y)
890 RETURN

900 ' ******  PSET ON TV SCREEN *****
910 Y = 128
920 X = AUPTPX(3, Y, X, 1, Y)
930 RETURN

950 ' ******  LINE ON TV SCREEN *****
952 POS1=Y1
954 POS2=X1
```

```
956 X = AUGPOS( Y, X, 3)
958 X = AULINE(1,POS1,D)
960 RETURN

970 ' ****** BOX ON TV SCREEN *****
976 X = AUGPOS( Y1, X1, 3)
978 X = AUBOX(Y2-Y1,X2-X1,D)
980 RETURN

1000 ' ***** INPUT INITIAL INFORMATION *********
1010 KEY OFF:SCREEN 9:CLS:LOCATE 5,5:INPUT" ENTER TEST NUMBER "; NUM
1020 FILE$="INDAT"+RIGHT$(STR$(1000+NUM),3)+".DAT"
1030 OPEN FILE$ FOR INPUT AS #1
1040 LINE INPUT #1, A$
1050 LINE INPUT #1, B$
1060 LINE INPUT #1, C$
1070 LINE INPUT #1, D$
1080 LINE INPUT #1, E$
1090 LINE INPUT #1, F$
1100 LINE INPUT #1, G$
1110 LINE INPUT #1, H$
1120 LINE INPUT #1, I$
1130 LINE INPUT #1, J$
1140 LINE INPUT #1, K$
1150 CLOSE #1
1160 ' ***** CONVERT TO NUMBERS ******
1170 WSPEED=VAL(D$)
1180 WDIR=VAL(E$)
1190 FCAMDIR=VAL(F$)
1200 FCAMDIS=VAL (G$)
1210 SCAMDIR=VAL(H$)
1220 SCAMDIS=VAL(I$)
1230 TESTLEN=VAL(J$)
1240 INC=VAL(K$)
1250 ' ***** DISPLAY INFORHATION *******
1260 SCREEN 9:cls
1270 COLOR 15:LOCATE 1,20:PRINT " NIST FIRE PLUME CALCULATOR"
1275 COLOR 7:LOCATE 3,5:PRINT " TEST NUMBER : ";NUM
1280 COLOR 7:LOCATE 4,5:PRINT " DATE OF TEST : ";A$
1290 COLOR 7:LOCATE 5,5:PRINT " TIME OF TEST : ";B$
1300 COLOR 7:LOCATE 7,5:PRINT " TESTS DESCRIPTION : ";C$
1310 COLOR 7:LOCATE 9,5:PRINT " WIND SPEED : ";D$;" m / sec"
1320 COIDR 7:LOCATE 10,5:PRINT " WIND DIRECTION : ";E$;" degrees"
1330 COIDR 7:LOCATE 12,5:PRINT " FRONT VIEW CAMERA DIRECTION : ";F$;" degrees"
1340 COLOR 7:LOCATE 13,5:PRINT " FRONT VIEW CAMERA DISTANCE : ";G$;" m"
1350 COLOR 7:LOCATE 14,5:PRINT " SIDE VIEW CAMERA DIRECTION : ";H$;" degrees"
1360 COLOR 7:LOCATE 15,5:PRINT " SIDE VIEW CAMERA DISTANCE : ";I$;" m"
1370 COLOR 7:LOCATE 17,5:PRINT " TEST LENGTH : ";J$;" seconds"
1380 COLOR 7:LOCATE 18,5:PRINT " TIME STEP : ";K$;" seconds"
1390 COLOR 9:LOCATE 22,5:PRINT " CHECK ALL OF THE ABOVE INFORMATION"
1400 COIDR 9:LOCATE 23,5:PRINT " PRESS C TO CONTINUE OR E TO EXIT PROGRAM"
1410 COLOR 15
1420 R$=INKEY$
1430 IF R$="c" OR R$="C" THEN GOTO 1460
1440 IF R$="e" OR R$="E" THEN SYSTEM
1450 GOTO 1420
1460 CLS
5000 ' ***** FRONT VIEW ANALYSIS *****
5100 'TESTLEN = 4: INC = 2
5101 SCREEN 9: KEY OFF: CLS
5400 COLOR 7: LOCATE 20, 1: PRINT " INSERT THE VIDEO TAKEN PERPENDICULAR TO THE
5410 COLOR 9: LOCATE 22, 5: PRINT " PRESS C TO CONTINUE WHEN READY OR R TO RETUR
5415 COLOR 15
5420 R$ = INKEY$
5430 IF R$ = "c" OR R$ = "C" THEN GOTO 5460
5440 'IF R$="r" OR R$="R" THEN GOTO TOP
```

```
5450 GOTO 5420
5460 FOR B = 1 TO 640 STEP 16: LINE (I, 238)-(B, 349), 0, BF: NEXT B
5470 GOSUB 8000
5500 FOR FVIEW = INC TO TESTLEN STEP INC
5502 T$=RIGHT$(STR$(100+fview\60),2)+":"+RIGHT$(STR$(100+ fview MOD 60),2)
5505 COLOR 7: LOCATE 20, 20: PRINT " FORWARD VIDEO TO TIME = ";t$
5510 COLOR 9: LOCATE 22, 5: PRINT " PRESS C TO CONTINUE WHEN READY OR R TO RETUR
5515 COLOR 15
5520 R$ = INKEY$
5530 IF R$ = "c" OR R$ = "C" THEN GOTO 5560
5540 IF R$ = "r" OR R$ = "R" THEN GOTO 5000
5550 GOTO 5520
5560 FILEA$ = "F"+ RIGHT$(STR$(1000+NUM),3) + RIGHT$(STR$(10000+FVIEW), 4) + ".D
5580 GOSUB 8035
5590 NEXT FVIEW
6000 ' *****   SIDE VIEW ANALYSIS *****
6101 SCREEN 9: KEY OFF: CLS
6400 COLOR 7: LOCATE 20, 3: PRINT " INSERT THE VIDEO TAKEN PARALLEL TO THE WIND
6410 COLOR 9: IDCATE 22, 5: PRINT " PRESS C TO CONTINUE WHEN READY OR R TO RETUR
6415 COLOR 15
6420 R$ = INKEY$
6430 IF R$ = "c" OR R$ = "C" THEN GOTO 6460
6440 'IF R$="r" OR R$="R" THEN GOTO TOP
6450 GOTO 6420
6460 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
6470 GOSUB 8000
6500 FOR SVIEW = INC TO TESTLEN STEP INC
6502 T$=RIGHT$(STR$(100+sview\60),2)+":"+RIGHT$(STR$(100+ sview MOD 60),2)
6505 COLOR 7: LOCATE 20, 20: PRINT " FORWARD VIDEO TO TIME = ";t$
6510 COLOR 9: LOCATE 22, 5: PRINT " PRESS C TO CONTINUE WHEN READY OR R TO RETUR
6515 COLOR 15
6520 R$ = INKEY$
6530 IF R$ = "c" OR R$ = "C" THEN GOTO 6560
6540 IF R$ = "r" OR R$ = "R" THEN GOTO 6000
6550 GOTO 6520
6560 FILEA$ = "S" + RIGHT$(STR$(1000+NUM),3) + RIGHT$(STR$(10000+SVIEW), 4) - ".
6580 GOSUB 8035
6590 NEXT SVIEW
7000 GOT0 1000
8000 ' ********  INITIAL SCREEN GRAP AND SCALING  ********
8001 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
8002 COIDR 7: LOCATE 20, 13: PRINT " ADJUST THE HEIGHT OF THE CURSOR TO THE BASE
8003 COLOR 9: IDCATE 22, 28: PRINT " PRESS P WHEN IN POSITION"
8004 GOSUB 9000 ' ******* yorigin AND SCALING SUBROUTINE *******
8005 YORIGIN = CROSS(2, 2): XORIGIN = CROSS(2 , 1)
8010 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
8012 COLOR 7: LOCATE 20, 16: PRINT " ADJUST THE HEIGHT OF THE CURSOR TO A KNOWN
8014 COLOR 9: LOCATE 22, 28: PRINT " PRESS P WHEN IN POSITION"
8016 GOSUB 9050 ' ******* yorigin AND SCALING SUBROUTINE *******
8018 KNOWN = CROSS(2, 2)
8020 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
8022 COLOR 9: LOCATE 21, 10: INPUT " ENTER THE HEIGHT OF OBJECT IN METERS"; HEIG
8025 IF (YORIGIN - KNOWN)<1 THEN GOTO 8500
8030 SCALE = HEIGHT / (YORIGIN - KNOWN)
8031 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
8032 RETURN
8035 ' ******** NORMAL SCREEN GRAP ********
8037 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
8040 COIDR 7: IDCATE 20, 11: PRINT " ADJUST THE HEIGHT OF THE CURSOR TO THE UPPE
8042 COLOR 9: IDCATE 22, 28: PRINT " PRESS P WHEN IN POSITION"
8044 GOSUB 9000 ' ******* yorigin AND SCALING SUBROUTINE *******
8046 YMAX = INT(CROSS(2, 2)/4)*4: XMIN = INT(CROSS(2, 1)/4)*4
8048 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
8050 COLOR 7: LOCATE 20, 10: PRINT " ADJUST THE HEIGHT OF THE CURSOR TO THE LOWE
8052 COLOR 9: LOCATE 22, 28: PRINT " PRESS P WHEN IN POSITION"
8056 GOSUB 40000 ' ******* yorigin AND SCALING SUBROUTINE *******
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8058 YMIN = INT(CROSS(2, 2)/4)*4: XMAX = INT(CROSS(2, 1)/4)*4
8060 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(E, 349), 0, BF: NEXT B
8100 SEN = 90
8101 LINE (64, 1)-(576, 237), 15, BF
8102 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
8105 SEN = SEN + 10: GOSUB 20005' *** CALL VIDEO AND DISPLAY DATA FILE ***
8110 COLOR 7: LOCATE 19, 11: PRINT " ANALYZE THE VIDEO IMAGE OVERLAYED ON THE AD
8112 COLOR 9: LOCATE 20, 12: PRINT " PRESS I TO INCREASE OR D TO DECREASE THE SE
8114 COLOR 9: IDCATE 21, 21: PRINT " PRESS C TO USE THE CAPTUED IMAGE"
8116 COLOR 9: LOCATE 22, 24: PRINT " PRESS M TO MODIFY THE IMAGE"
8120 COLOR 9: IDCATE 23, 22: PRINT " PRESS R TO REDO FROM THE START"
8125 R$ = INKEY$
8130 IF R$ = "c" OR R$ = "C" THEN GOTO 8200
8135 IF R$ = "i" OR R$ = "I" THEN GOTO 8102' *** INCREASE INTENSITY ***
8140 IF R$ = "d" OR R$ = "D" THEN GOSUB 21000: GOTO 8110' *** DECREASE INTENSITY
8145 IF R$ = "m" OR R$ = "M" THEN GOSUB 31000: GOTO 8180' *** MODIFY THE IMAGE *
8148 IF R$ = "r" OR R$ = "R" THEN GOTO 8170' *** REDO FROM THE START ***
8150 GOTO 8125
8170 X = AUBCLR(3)
8174 GOTO 8100
8180 IF R=l THEN GOTO 8170
8200 '****** SAVE DATA ********
8205 CLS:LINE(1,1)-(639,300),3,BF
8210 COLOR 4:LOCATE 23,31:PRINT "CAPTURING IMAGE"
8240 OPEN FILEA$ FOR OUTPUT AS #1
8250 PRINT #1 ,SCALE*4,1+(XMAX-XMIN)\4,1+(YMIN-YMAX)\4
8260 FOR ROW = YMIN TO YMAX STEP -4
8270 FOR COL = XMIN TO XMAX STEP 4
8280 PRINT #1,D(COL / 4, ROW / 4);
8290 IF D(COL / 4, ROW / 4)=1 THEN LINE (64 + COL, ROW / 2 + 2)-(64 + COL + 3, (
8300 NEXT COL
8305 PRINT 11,
8310 NEXT ROW
8320 CLOSE #1
8325 CLS
8330 RETURN
8500 ' ****** POOR SCALING LOGIC ******
8510 BEEP
8520 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
8530 COLOR 4: LOCATE 20, 21: PRINT " THE SCALING LOGIC IS INCORRECT"
8540 COLOR 7: IDCATE 21, 5: PRINT " THE BASE OF THE FIRE AND THE KNOWN HEIGHT CA
8550 COLOR 9: IDCATE 23, 27: PRINT " PRESS C TO CONTINUE"
8560 R$ = INKEY$
8570 IF R$ = "c" OR R$ = "C" THEN GOTO 8000
8580 GOTO 8560
9000 ' ******* yorigin AND SCALING SUBROUTINE *******
9010 'SCREEN 9:KEY OFF:CLS
9020 GOSUB 475 ' **** SCREEN GRAB *****
9030 CROSS(1, 1) = 80: CROSS(1, 2) = 246
9040 CROSS(2, 1) = 80: CROSS(2, 2) = 246
9050 'LINE(64,1)-(577,258),7,B
9060 'LINE (CROSS(1,1) -10,CROSS(1,2))-(CROSS(1,1)+10,CROSS(1,2)) ,0
9070 'LINE (CROSS(1,1),CROSS(1,2) -10)-(CROSS (1,1) ,CROSS(1,2)+10) ,0
9080 'LINE(CROSS(2,1) -10,CROSS(2,2))-(CROSS(2,1)+10,CROSS(2,2)),9
9090 'LINE(CROSS(2,1),CROSS(2,2)-10)-(CROSS(2,1),CROSS(2,2)+10),9
9091  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2): GOSUB 850
9092  Y = 127: COL = CROSS(1, 1) + 2: ROW = CROSS(1, 2): GOSUB 850
9093  Y = 127: COL = CROSS(1, 1) - 2: ROW = CROSS(1, 2): GOSUB 850
9094  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2) + 2: GOSUB 850
9095  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2) - 2: GOSUB 850
9096  Y = 128: COL = CROSS(2, 1): ROW = CROSS(2, 2): GOSUB 800
9097  Y = 128: COL = CROSS(2, 1) + 2: ROW = CROSS(2, 2): GOSUB 800
9098  Y = 128: COL = CROSS(2, 1) - 2: ROW = CROSS(2, 2): GOSUB 800
9099  Y = 128: COL = CROSS(2, 1): ROW = CROSS(2, 2) + 2: GOSUB 800
9100  Y = 128: COL = CROSS(2, 1): ROW = CROSS(2, 2) - 2: GOSUB 800
9105 CROSS(1, 1) = CROSS(2, 1)
```

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9110 CROSS(1, 2) = CROSS(2, 2)
9120 R$ = INKEY$
9170 IF R$ = CHR$(0) + "M" AND CROSS(2, 1) < 506 THEN CROSS(2, 1) = CROSS(1, 1)
9175 IF R$ = CHR$(0) + "K" AND CROSS(2, 1) > 5 THEN CROSS(2, 1) = CROSS(1, 1) -
9180 IF R$ = CHR$(0) + "P" AND CROSS(2, 2) < 509 THEN CROSS(2, 2) = CROSS(1, 2)
9185 IF R$ = CHR$(0) + "H" AND CROSS(2, 2) > 3 THEN CROSS(2, 2) = CROSS(1, 2) -
9190 IF R$ = "6" AND CROSS(2, 1) < 495 THEN CROSS(2, 1) = CROSS(1, 1) + 16: GOTO
9195 IF R$ = "4" AND CROSS(2, 1) > 16 THEN CROSS(2, 1) = CROSS(1, 1) - 16: GOTO
9200 IF R$ = "2" AND CROSS(2, 2) < 495 THEN CROSS(2, 2) = CROSS(1, 2) + 16: GOTO
9205 IF R$ = "8" AND CROSS(2, 2) > 16 THEN CROSS(2, 2) = CROSS(1, 2) - 16: GOTO
9210 IF R$ = "P" OR R$ = "p" THEN GOTO 9300
9220 GOTO 9100
9300  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2): GOSUB 850
9302  Y = 127: COL = CROSS(1, 1) + 2: ROW = CROSS(1, 2): GOSUB 850
9304  Y = 127: COL = CROSS(1, 1) - 2: ROW = CROSS(1, 2): GOSUB 850
9306  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2) + 2: GOSUB 850
9308  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2) - 2: GOSUB 850
9310 RETURN
20000 ' *** CALL VIDEO AND DISPLAY DATA FILE ***
20002 GOSUB 475 ' **** SCREEN GRAB *****
20004 LINE (64, 1)-(576, 257), 15, BF
20005 FOR I = 1 TO 128
20010 FOR J = 1 TO 128
20015 D(i,j)=0
20020 NEXT J
20025 NEXT I
20040 FOR ROW = YMIN TO YMAX STEP -4
20050 FOR COL = XMIN TO XMAX STEP 4
20070 GOSUB 700
20080 IF Z > SEN THEN GOTO 20100
20085 D(COL / 4, ROW / 4) = 1
20088 Y = 64: GOSUB 800
20095 LINE (64 + COL, ROW / 2 + 2)-(64 + COL + 3, (ROW + 3) / 2 + 2), 0, BF
20100 NEXT COL
20120 NEXT ROW
20130 RETURN
21000 ' DECREASE INTENSITY
21002 SEN = SEN - 10
21040 FOR ROW = YMIN TO YMAX STEP -4
21050 FOR COL = XMIN TO XMAX STEP 4
21070 GOSUB 700
21080 IF Z > SEN THEN GOTO 21088 ELSE GOTO 21100
21088 Y = 191: GOSUB 850
21090 D(COL / 4, ROW / 4) = 0
21095 LINE (64 + COL, ROW / 2 + 2)-(64 + COL + 3, (ROW + 3) / 2 + 2), 15, BF
21100 NEXT COL
21120 NEXT ROW
21125 RETURN
31000 ' ******  MODIFY IMAGE **********
31001 CROSS(1, 1) = XMIN: CROSS(1, 2) = YMIN
31002 CROSS(2, 1) = XMIN: CROSS(2, 2) = YMIN
31005 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
31010 COLOR 7: LOCATE 20, 18: PRINT " MOVE THE CURSOR TO THE DESIRED LOCATION"
31015 COLOR 9: LOCATE 21, 12: PRINT " PRESS -B- TO BOX -A- TO ADD OR -E- TO ERAS
31020 COLOR 9: LOCATE 22, 22: PRINT " PRESS C TO USE THE CAPTUED IMAGE"
31022 COLOR 9: LOCATE 23, 23: PRINT " PRESS R TO REDO FROM THE START"
31025  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2): GOSUB 850
31030  Y = 127: COL = CROSS(1, 1) + 2: ROW = CROSS(1, 2): GOSUB 850
31035  Y = 127: COL = CROSS(1, I) - 2: ROW = CROSS(1, 2): GOSUB 850
31040  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2) + 2: GOSUB 850
31045  Y = 127: COL = CROSS(1, 1): ROW = CROSS(1, 2) - 2: GOSUB 850
31050  Y = 128: COL = CROSS(2, 1): ROW = CROSS(2, 2): GOSUB 800
31055  Y = 128: COL = CROSS(2, 1) + 2: ROW = CROSS(2, 2): GOSUB 800
31060  Y = 128: COL = CROSS(2, 1) - 2: ROW = CROSS(2, 2): GOSUB 800
31065  Y = 128: COL = CROSS(2, 1): ROW = CROSS(2, 2) + 2: GOSUB 800
31070  Y = 128: COL = CROSS(2, 1): ROW = CROSS(2, 2) - 2 GOSUB 800
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31075 CROSS(1, 1) = CROSS(2, 1)
31080 CROSS(1, 2) = CROSS(2, 2)
31085 R=0 :R$=INKEY$
31090 IF R$ = CHR$(0) + "M" AND CROSS(2, 1) < 506 THEN CROSS(2, 1) = CROSS(1, 1)
31095 IF R$ = CHR$(0) + "K" AND CROSS(2, 1) > 5 THEN CROSS(2, 1) = CROSS(1, 1) -
31100 IF R$ = CHR$(0) + "P" AND CROSS(2, 2) < 509 THEN CROSS(2, 2) = CROSS(1, 2)
31105 IF R$ = CHR$(0) + "H" AND CROSS(2, 2) > 3 THEN CROSS(2, 2) = CROSS(1, 2) -
31110 IF R$ = "6" AND CROSS(2, 1) < 495 THEN CROSS(2, 1) = CROSS(1, 1) + 16: GOT
31115 IF R$ = "4" AND CROSS(2, 1) > 16 THEN CROSS(2, 1) = CROSS(1, 1) - 16: GOTO
31120 IF R$ = "2" AND CROSS(2, 2) < 495 THEN CROSS(2, 2) = CROSS(1, 2) + 16: GOT
31125 IF R$ = "8" AND CROSS(2, 2) > 16 THEN CROSS(2, 2) = CROSS(1, 2) - 16: GOTO
31130 IF R$ = "c" OR R$ = "C" THEN RETURN
31132 IF R$ = "b" OR R$ = "B" THEN GOTO 41000' *** BOX ***
31135 IF R$ = "a" OR R$ = "A" THEN GOTO 31600' *** ADD A POINT ***
31140 IF R$ = "e" OR R$ = "E" THEN GOTO 31500' ***ERASE A POINT ***
31145 IF R$ = "r" OR R$ = "R" THEN R=1 :RETURN' *** REDO FROM THE START **f
31150 GOTO 31085
31500 ' **** ERASE A POINT ****
31505 Y = 191: COL = CROSS(1, 1): ROW = CROSS(1, 2): GOSUB 850
31510 D(COL / 4, ROW / 4) = 0
31515 LINE (64 + COL, ROW / 2 + 2)-(64 + COL + 3, (ROW + 3) / 2 + 2), 15, BF
31520 GOTO 31085
31600 ' **** ADD A POINT ****
31605 Y = 64: COL = CROSS(1, 1): ROW = CROSS(1, 2): GOSUB 800
31610 D(COL / 4, ROW / 4) = 1
31615 LINE (64 + COL, ROW / 2 + 2)-(64 + COL + 3, (ROW + 3) / 2 + 2), 0, BF
31620 GOTO 31085

40000 ' ******* BOX DRAW SUBROUTINE *******
40005 X1=XMIN:Y1=YMAX
40010 D=0:X2=CROSS(1,1):Y2=CROSS(1,2):GOSUB 970
40020 D=1:X2=CROSS(2,1):Y2=CROSS(2,2):GOSUB 970
40030 CROSS(1, 1) = CROSS(2, 1)
40040 CROSS(1, 2) = CROSS(2, 2)
40220 R$ = INKEY$
40230 IF R$ = CHR$(0) + "M" AND CROSS(2, 1) < 506 THEN CROSS(2, 1) = CROSS(1, 1)
40240 IF R$ = CHR$(0) + "K" AND CROSS(2, 1) > 5 THEN CROSS(2, 1) = CROSS(1, 1) -
40250 IF R$ = CHR$(0) + "P" AND CROSS(2, 2) < 509 THEN CROSS(2, 2) = CROSS(1, 2)
40260 IF R$ = CHR$(0) + "H" AND CROSS(2, 2) > 3 THEN CROSS(2, 2) = CROSS(1, 2) -
40270 IF R$ = "6" AND CROSS(2, 1) < 495 THEN CROSS(2, 1) = CROSS(1, 1) + 32: GOT
40280 IF R$ = "4" AND CROSS(2, 1) > 16 THEN CROSS(2, 1) = CROSS(1, 1) - 32: GOTO
40290 IF R$ = "2" AND CROSS(2, 2) < 495 THEN CROSS(2, 2) = CROSS(1, 2) + 32: GOT
40300 IF R$ = "8" AND CROSS(2, 2) > 16 THEN CROSS(2, 2) = CROSS(1, 2) - 32: GOTO
40310 IF R$ = "P" OR R$ = "p" THEN GOTO 40330
40320 GOTO 40220
40330 D=0:X2=CROSS(1,1):Y2=CROSS(1,2):GOSUB 970
40340 RETURN


41000 ' ********* BOX MODIFY *********
41010 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
41020 COLOR 7: LOCATE 20, 11: PRINT " ADJUST THE HEIGHT OF THE CURSOR TO THE UPP
41030 COLOR 9: LOCATE 22, 28: PRINT " PRESS P WHEN IN POSITION"
41040 GOSUB 9050 ' ******* UPPER LEFT *******
41050 NYMAX = INT(CROSS(2, 2)/4)*4: NXMIN = INT(CROSS(2, 1)/4)*4
41060 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
41070 COLOR 7: LOCATE 20, 10: PRINT " ADJUST THE HEIGHT OF THE CURSOR TO THE LOW
41080 COLOR 9: LOCATE 22, 28: PRINT " PRESS P WHEN IN POSITION"
41090 X1=NXMIN:Y1=NYMAX:GOSUB 40010 ' ******* LOWER RIGHT *******
41100 NYMIN = INT(CROSS(2, 2)/4)*4: NXMAX = INT(CROSS(2, 1)/4)*4
41110 FOR B = 1 TO 640 STEP 16: LINE (1, 238)-(B, 349), 0, BF: NEXT B
41120 COLOR 9: LOCATE 21, 25: PRINT " PRESS -A- TO ADD OR -E- TO ERASE "
41130 R=0:R$=INKEY$
41140 IF R$ = "a" OR R$ = "A" THEN GOTO 41600' *** ADD A POINT ***
41150 IF R$ = "e" OR R$ = "E" THEN GOTO 41500' *** ERASE A POINT ***
```

```
41160 GOTO 41130

41500 ' ***** ERASE A BLOCK *******
41510 FOR ROW = NYMIN TO NYMAX STEP -4
41520 FOR COL = NXMIN TO NXMAX STEP 4
41530  Y = 191: GOSUB 850
41540 D(COL / 4, ROW / 4) = 0
41550 LINE (64 + COL, ROW / 2 + 2)-(64 + COL + 3, (ROW + 3) / 2 + 2), 15, BF
41560 NEXT COL
41570 NEXT ROW
41580 GOTO 31000

41600 ' ***** ADD A BLOCK *******
41610 FOR ROW = NYMIN TO NYMAX STEP -4
41620 FOR COL = NXMIN TO NXMAX STEP 4
41630  Y = 64: GOSUB 800
41640 D(COL / 4, ROW / 4) = I
41650 LINE (64 + COL, ROW / 2 + 2)-(64 + COL + 3, (ROW + 3) / 2 + 2), 0, BF
41660 NEXT COL
41670 NEXT ROW
41680 GOTO 31000
```

Appendix D

Smoke Plume Volume and Trajectory Model

User’s Manual

January 31, 1992

Developed by

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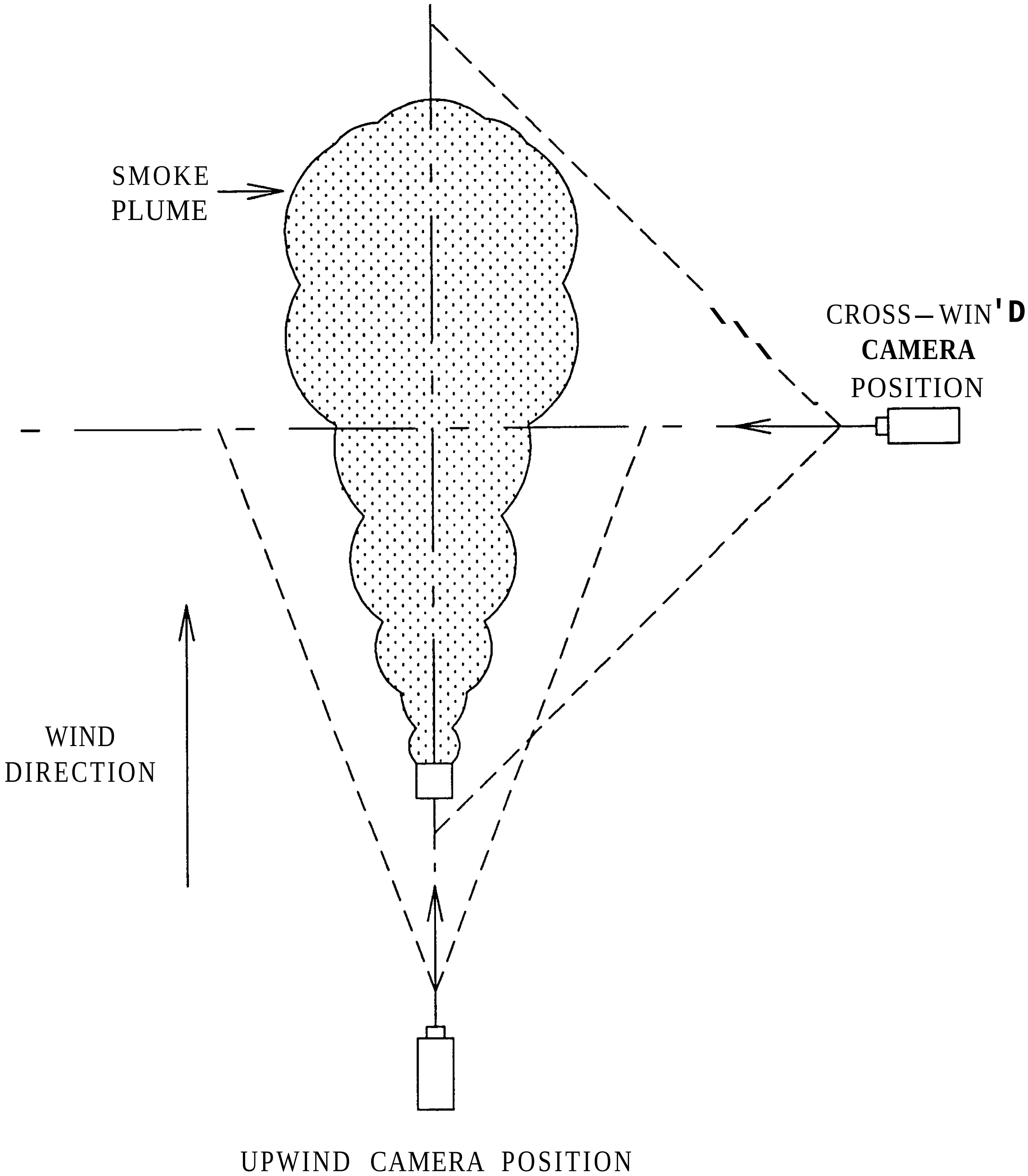
Figures

INTRODUCTION

Considerable research has been conducted regarding the burning of crude oil at sea as a means to mitigate oil spills. A significant part of this research has been conducted by the Building and Fire Research Laboratory (BFRL) at the National Institute of Standards and Technology (NIST) for the United States Minerals Management Service (MMS), the United States Coast Guard (USCG), and the American Petroleum Institute (API). Through the use of small scale experiments and a series of large scale field tests, the understanding of the burning process of crude oil on water has been increased. These studies included investigation of burning rate, fire radiation, smoke emission, smoke composition, and smoke dispersion in the atmosphere. Much of the attention has focussed on the development of a computer model which could provide a reasonably accurate assessment of the volume of smoke produced and the trajectory of the smoke plume resulting from an oil spill fire. This model may also be capable of backing-out the quantity of oil burning by the volume of smoke being produced.

A computer model has been developed to digitize 8 mm video images of smoke plumes and provide the user with options to analyze and manipulate the plume data. The model requires two recorded video images, one upwind and one crosswind of the plume as shown in Figure 1. The crosswind camera records the width, leading edge, and height of the smoke plume, while the upwind camera records the width and height of the plume. The volume of the smoke plume is calculated using both a one-view and a two-view approach.

For the one-camera approach, a center-line-trajectory method is used to calculate the volume from the front camera view. The user is asked to input a center line for the smoke plume on the video screen. **A** radius perpendicular to the center line *is* determined to the edge of the smoke plume. The radii along a discrete line segment are averaged together, and then the volume of the plume **is** determined as **solid** cylindrical shapes. These are then summed up to calculate the total volume. The center line method is also the driving logic for determining the trajectory of the smoke plume. In the two-camera approach, the cameras are positioned approximately 90 degrees apart, one



Plan View

Fig. 1 - **Preferred video camera orientations**

upwind from the plume and the other perpendicular. From these two views, the cross-sectional areas of the plume are calculated as elliptical sections. If the two cameras are not perpendicular and parallel to the smoke plume, the values are adjusted accordingly. A set height increment is used to divide the plume into equal sections. The volume is then calculated from the widths determined by the crosswind and upwind camera using the equation for the area of an ellipse and multiplying by the height increment, i.e. $V = (\pi ab)/4*dy$, where "a" is the width of the plume from the crosswind camera and "b" is the width from the upwind camera. The "dy" variable is the predetermined height increment. If the smoke plume exceeds the video screen for the upwind view, the previously determined width is used in the succeeding calculations of the plume volume and production rate through the end of the test run.

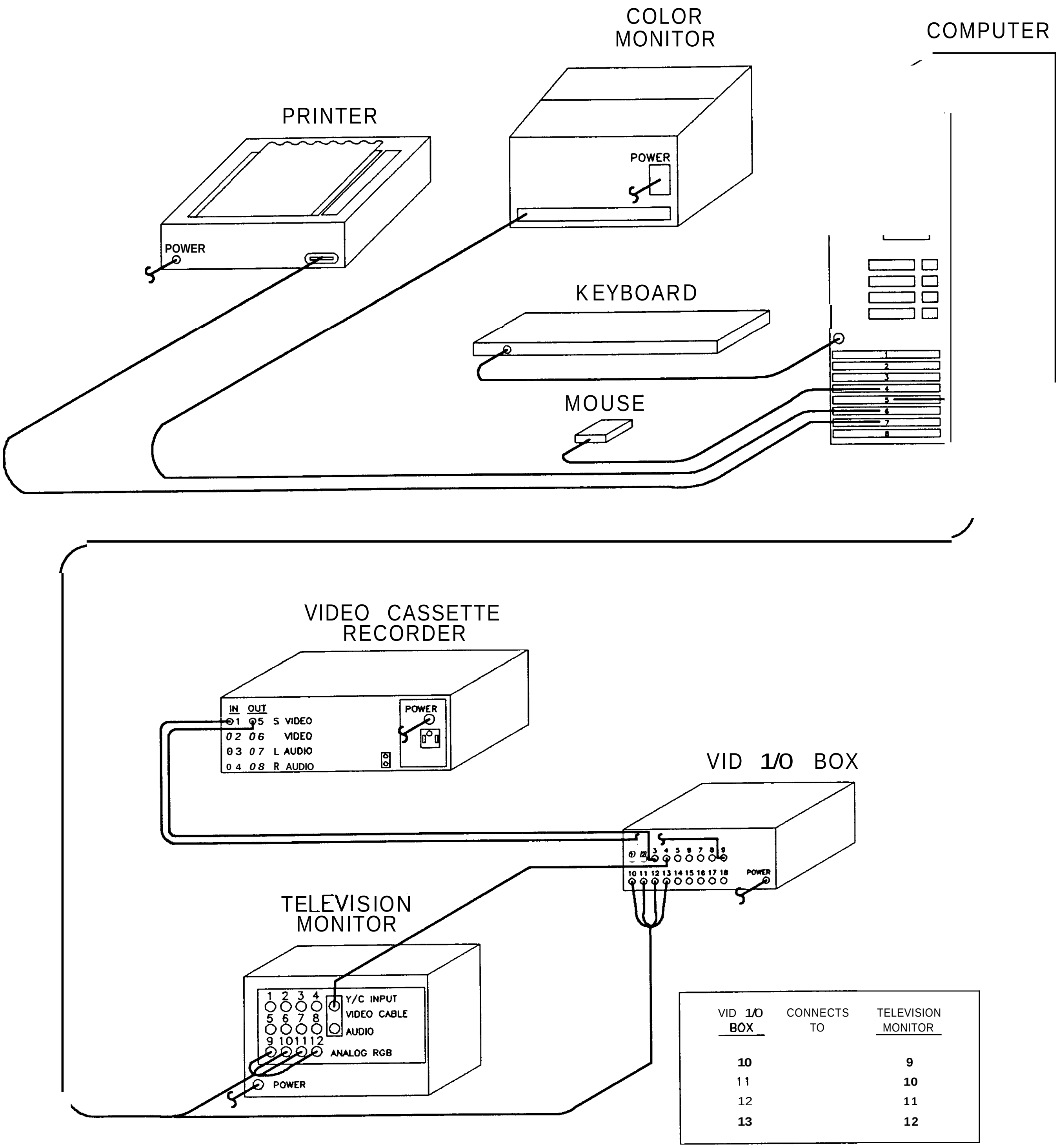
VIDEO TAPING THE PLUME

As stated previously, the computer model requires two video tapes, one upwind and the other crosswind from the plume. This should position the cameras facing approximately 90° apart. If conditions do not permit such positioning, then the cameras should be placed as close to these conditions as possible. Deviation from these desired positions may decrease the accuracy of the results. Both video cameras should be positioned far enough away from the fire to assure that the smoke plume does not leave the field of view. The following is a good rule of thumb for positioning the video cameras: <u>the width of the view is equivalent to the distance from the fire and the height of view is approximately 80% of the distance from the fire</u>. An object of a known height must also be visible to each camera. This height will later be used to scale the image during the volume calculations. It is recommended that the height of the object be greater than one-half the height of the screen.

Both cameras should be started at least one minute before ignition. This allows for easy synchronization of the video images using the ignition as time zero. If possible, the cameras should be mounted on a tripod and should not be moved until the test is complete (the fire is out).

GETTING STARTED–SETUP/WIRING DIAGRAM

A detailed description of the hardware configurations are shown in the manuals for the various pieces of hardware making up the system. A quick reference wire diagram has been produced from this information and is shown in Fig. 2.



VID I/O BOX	CONNECTS TO	TELEVISION MONITOR
10		9
11		10
12		11
13		12

Fig. 2 - Setup/wiring diagram

RUNNING THE PROGRAMS

Initial Information

The computer model requires a description of the ambient conditions and the camera locations during the fire. The file can be produced using any full screen editor. Word processing packages are not recommended due to their use of control characters. The file should be named as follows:

FILE NAME "INDAT???.DAT"
i.e., TEST #1 - INDATØØØ.DAT

If the test number has fewer than three digits, zeros (Ø) must be present.

A description of the variables along with a sample data file is listed below. Descriptive variables such as the test description may only contain up to 256 characters. Numeric variables are in standard SI units and may contain decimal points but are not required.

VARIABLE	SAMPLE DATA FILE
TEST NO:	2
DATE OF TEST (UP TO 256 CHARACTERS)	4/17/91
TIME OF TEST (UP TO 256 CHARACTERS)	10:00
TEST DESCRIPTION (UP TO 256 CHARACTERS)	7x7 m PAN
WIND SPEED - M/SEC	2.2
WIND DIRECTION COMPASS HEADING IN DEGREES	108
FRONT VIEW CAMERA DIRECTION COMPASS HEADING IN DEGREES	75
FRONT VIEW CAMERA DISTANCE - METERS	650
SIDE VIEW CAMERA DIRECTION COMPASS HEADING IN DEGREES	330
SIDE VIEW CAMERA DISTANCE - METERS	120
TEST LENGTH - SECONDS	60
TIME STEP - SECONDS	30
FLAG FOR PRINTOUT I-YES 0-NO	1

Analyzing **the** Video Image

The video image manipulation and storage program flow chart is shown in Fig. **3. A** listing of the program is found in Appendix C of the report, "Development of a Video Image-based Methodology for Estimating Large Scale Hydrocarbon Smoke Plume Size and Extent." To begin the video imaging program, type "**VIDEO,**" and then press **ENTER.** The following is a list of screens in the order in which they will appear as the program is executed. The bold-type print are commands displayed on the computer screen.

ENTER TEST NUMBER ?

The test number corresponds to the data file previously made containing all of the background information. The test number must be an integer from **1-999.** After the number has been typed, press **ENTER** to continue.

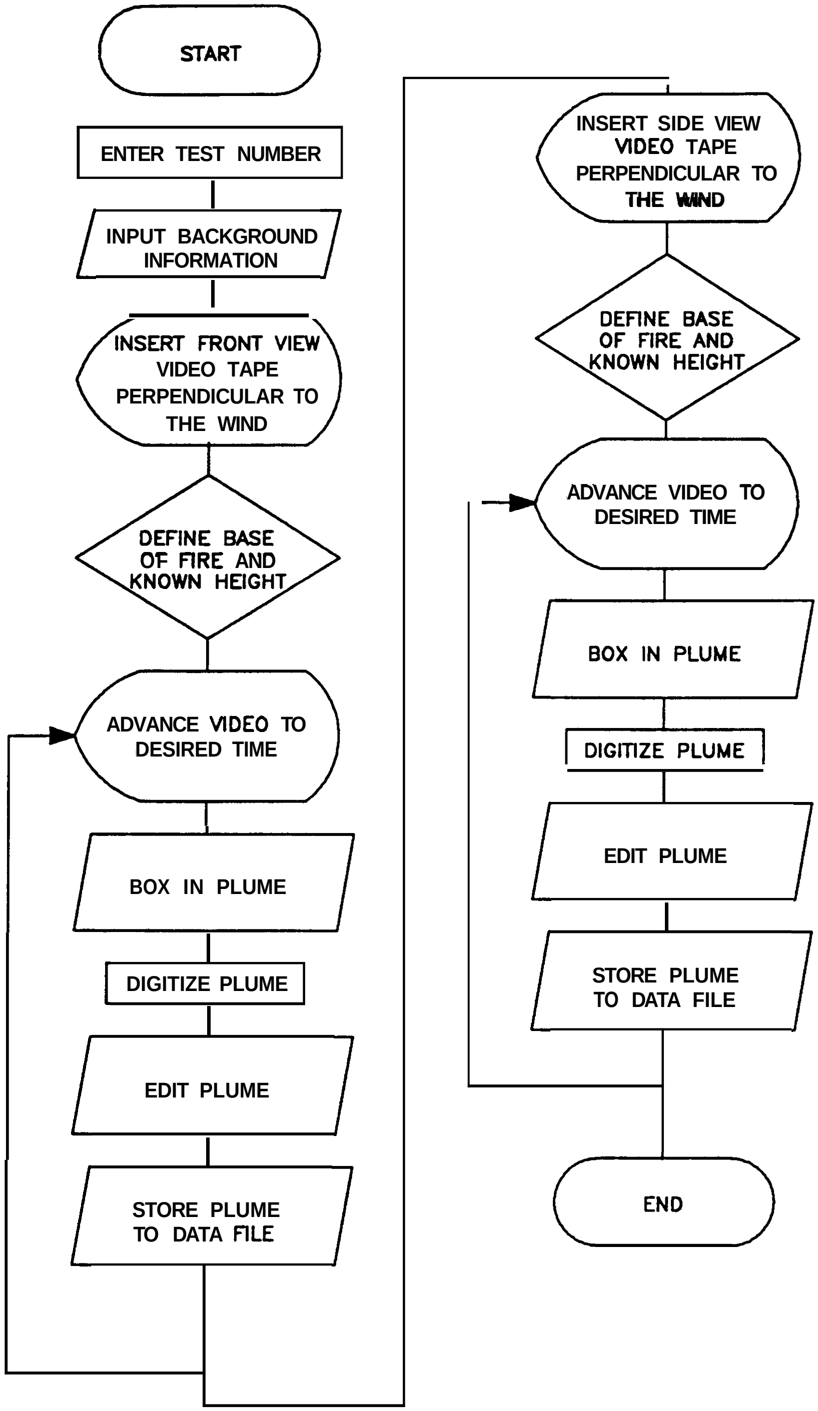


Fig. 3 - Video image manipulation and storage program flow chart

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER: 8
DATE OF TEST: 5/31/91
TIME OF TEST: 9:45

TEST DESCRIPTION: 50 FT BY 50 FT POOL FIRE

WIND SPEED: 1 m/sec
WIND DIRECTION: 110 degrees

FRONT VIEW CAMERA DIRECTION: 240 degrees
FRONT VIEW CAMERA DISTANCE: 3500 m
SIDE VIEW CAMERA DIRECTION: 42 degrees
SIDE VIEW CAMERA DISTANCE: 650 m

TEST LENGTH: 60 seconds
TIME STEP: 30 seconds

CHECK ALL OF THE ABOVE INFORMATION
PRESS C TO CONTINUE OR E TO EXIT PROGRAM

This initial screen displays the background data retrieved from the data file. Check the information to assure that it is correct. A capital or a small "C" will allow the user to continue. A capital or small "E" will exit the user to the operating system to make corrections in the data file.

INSERT THE VIDEO TAKEN PERPENDICULAR TO THE WIND DIRECTION INTO THE PLAYER

PRESS C TO CONTINUE WHEN READY OR R TO RETURN TO THE PREVIOUS MENU

This screen serves as a prompt to assure that the proper video tape is in the tape player and the player is on and operating properly. Press the **VTR** button under the input selection on the **TV** monitor to assure the video system is working properly. The tape should be at the beginning of the test and include a view of an object of known height (i.e. blimp). **A** capital or small "**C**" will allow the user to continue with the program. **A** capital or small "**R**" will return the user to the previous menu.

Whenever a cursor appears on the screen, the cursor can be moved using the arrow keys on the number pad of the keyboard. When the **"NUMLOCK"** key is turned off, the cursor moves in small increments, while when turned on the cursor moves in large increments.

ADJUST THE HEIGHT OF THE CURSOR TO THE BASE OF THE FIRE
PRESS P WHEN IN POSITION

This is the first screen in scaling the proceeding video images. Move the cursor to the base of the fire using the arrow keys as described above. When in position, press a capital or small "**P**" to proceed to the next screen.

ADJUST THE HEIGHT OF THE CURSOR TO A KNOWN HEIGHT
PRESS P WHEN IN POSITION

It is recommended that the object be over one-half the height of the screen. This will produce more accurate results than an object that is only a small percent of the height of the screen. Move the cursor using the arrow keys to a known height (i.e., blimp, tower, etc.). When in position, press a capital or small "**P**" to proceed to the next screen.

ENTER THE HEIGHT OF OBJECT IN METERS?

Enter the height of the object marked by the cursor in the previous screen. The height of the object should be input in meters. The height may contain a decimal point but is not required. Press **ENTER** to continue.

THE SCALING LOGIC IS INCORRECT
THE BASE OF THE FIRE AND THE KNOWN HEIGHT CAN NOT BE THE SAME POINT
PRESS C TO CONTINUE

If this screen appears, there is a problem in the scaling logic. Possible causes for such problems are as follows: the base of the fire and the known height falling at the same vertical location on the screen; or a zero input on the previous screen for the known height. **A** capital or small "**C**" will allow the user to repeat the scaling process.

FORWARD VIDEO TO TIME = 00:30
PRESS C TO CONTINUE WHEN READY OR R TO RETURN TO THE PREVIOUS MENU

This screen serves as a prompt to adjust the video to the sample location (desired time). The time displayed corresponds to the information present in the background data file. The time shown on the video player should correspond to the time of ignition plus the time above. The video frame grabber is more efficient when selecting a frame from moving video. **As** the tape plays to the desired time, press a capital or small "**C**" to capture the image. **A** capital or small "**R**" will return the user to the previous screen.

In most cases, it is desirable to stop the video after the screen has been digitized. This may speed up the time required to advance or rewind the video to the next sampling location. The acquired image is displayed by pressing the ANALOG/RGB button on the TV monitor. If no image is displayed, check the wiring using the wiring diagram found in this manual and rerun the program from the beginning.

ADJUST HEIGHT OF THE CURSOR TO THE UPPER LEFT BOUNDARY
PRESS P WHEN IN POSITION

This section of the program allows the user to select a specific section of the screen to be analyzed. This reduces the time to process the entire image and reduces the presence of other dark objects which may be interpreted as the plume. Move the cursor to the desired location using the arrow keys and press "P" when in position.

ADJUST THE HEIGHT OF THE CURSOR TO THE LOWER RIGHT BOUNDARY
PRESS P WHEN IN POSITION

Increase the size of the box to include the entire plume using the arrow keys. The tighter the box fits around the plume, the less editing will be required later. Press "P" when in position.

ANALYZE THE VIDEO IMAGE OVERLAYED ON THE ADJACENT MONITOR
PRESS I TO INCREASE OR D TO DECREASE SENSITIVITY
PRESS C TO USE THE CAPTURED IMAGE
PRESS M TO MODIFY THE IMAGE
PRESS R TO REDO FROM THE START

Once the plume has been bounded, the computer will analyze the image in the box and make a first cut at determining what portion of the video is plume. The computer will draw a series of white dots over the section of the video image on the TV screen in which it has determined *to* be the smoke plume. The sensitivity may be increased or decreased by pressing "I" or "D" accordingly. As before, the computer will recognize both capital or small letters. It is recommended that the user increase the intensity until all of the plume has been selected. Extraneous dots may be removed during the modification section of the program. If the user is satisfied with the image, pressing the letter "C" will cause the image to be stored to a data file for further manipulation. If changes are required, the image can be modified by pressing the letter "M."

MOVE THE CURSOR TO THE DESIRED LOCATION
PRESS -B- TO BOX -A- TO ADD OR -E- TO ERASE A POINT
PRESS C TO USE THE CAPTURED IMAGE
PRESS R TO REDO FROM THE START

If only a small area outside the plume has been captured, the data can easily be removed by moving the cursor to that location and by pressing the letter "E" to erase. The user can add a point to the plume in the same manner by pressing an "A." If a larger area exists, the user may want to select (box) an entire area to add or delete. This is accomplished by pressing the letter "B."

ADJUST THE HEIGHT OF THE CURSOR TO THE UPPER LEFT BOUNDARY
PRESS P WHEN IN POSITION

The procedure for boxing in an area is the same used to box in the plume. Move the cursor to the upper left boundary and press "P" when in position.

ADJUST THE HEIGHT OF THE CURSOR TO THE LOWER RIGHT BOUNDARY
PRESS P WHEN IN POSITION

Extend the box over the desired area and again press "**P**" when in position.

PRESS-A- TO ADD OR -E- TO ERASE

Once the area **is** bounded, the letter **"A"** will add the area to the plume or an "**E**" will remove it from the plume. This process may be repeated until all modifications are complete. Once the user is satisfied with the image, pressing the letter "**C**" will cause the image to be stored to a data file for further manipulation.

Once the image has been stored to a file, the computer will prompt the user to advance the video to the next time step, and the time capture process **is** repeated. When all the video images required from the first tape are complete. The computer will prompt the user to change tapes, and the process is again repeated.

INSERT THE VIDEO TAKEN PARALLEL TO THE WIND DIRECTION INTO THE PLAYER
PRESS C TO CONTINUE WHEN READY OR R TO RETURN TO THE PREVIOUS MENU

A sample Bit Map (data file) developed during this process is shown in Fig. **4.** Due to the manner in which the matrix of data is handled, the image is stored upside down and backwards. The nomenclature for the file is similar to the initial data file. The first character stands for front or side, the next three characters are the test number, and the final four are the time (seconds) into the fire from which the image was recorded. The first number in the data file is the scaling factor. Each number making up the plume

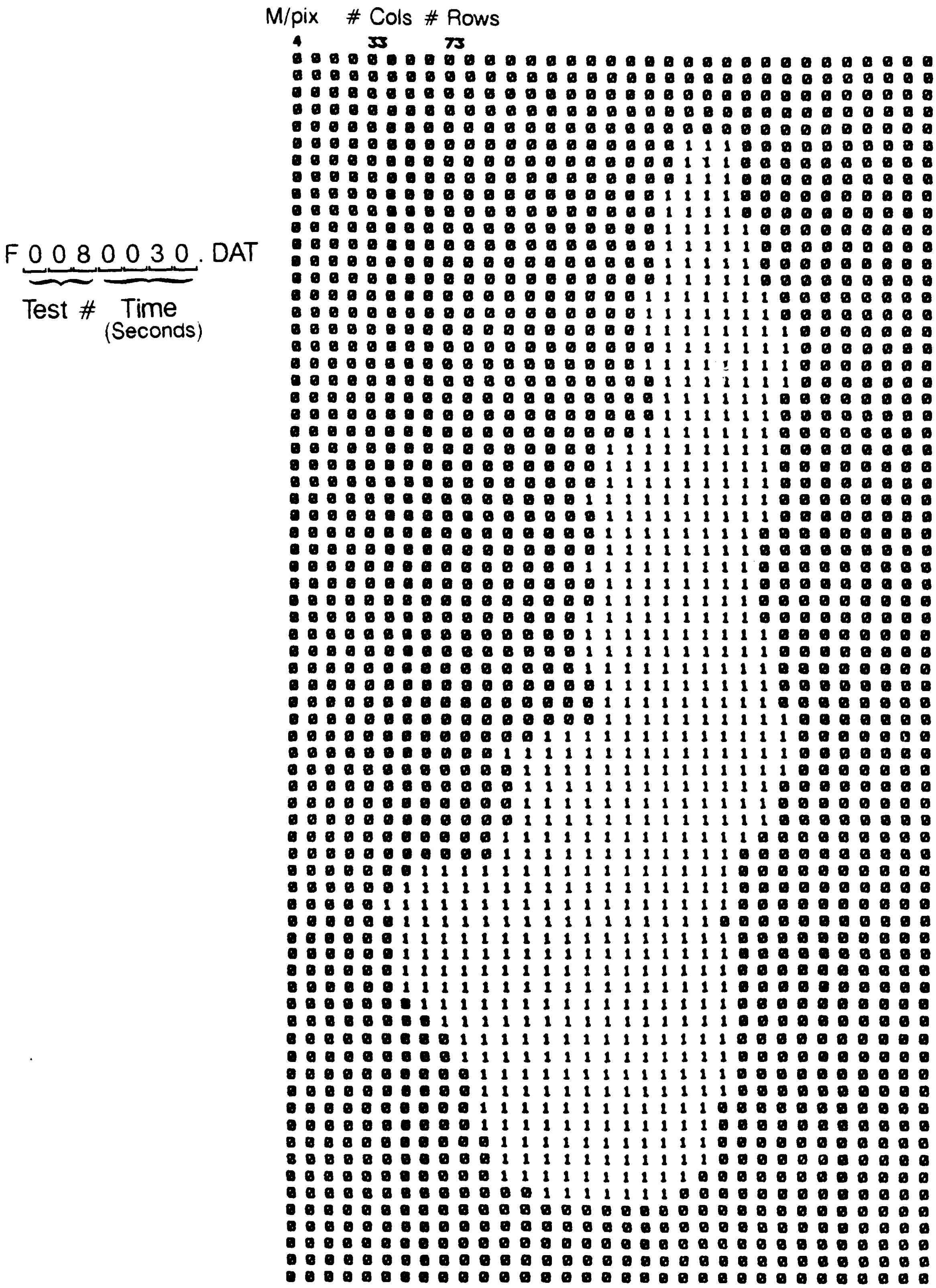


Fig. 4 - Sample bit map (data file)

represents **a** square with a side of many meters. The next two numbers are the number of columns and rows making up the image. The remaining numbers make up the image. The area representing the plume is depicted by the "**1**"**s** in the file.

Calculating the Volume and Trajectory of the Plume

The volume and trajectory calculation and output program flow chart is shown in Fig. 5. **A** listing of the program is found in Appendix C of the report, "Development of a Video Image-based Methodology for Estimating Large Scale Hydrocarbon Smoke Plume Size and Extent." To begin the computation program, type "**VOLUME**" then press **ENTER.**

ENTER TEST NUMBER ?

As before, the test number corresponds to the data file containing all of the background information. Now the stored images of the plume produced using the video imaging program should also be present. The test number must be an integer from 1-999. After the test number has been typed, press **ENTER** to continue.

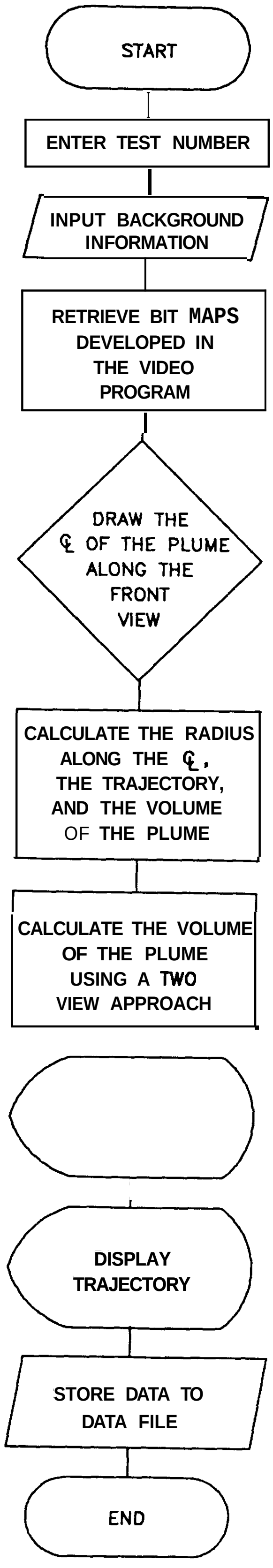


Fig. 5 - Calculation and output program flow chart

VISIBLE SMOKE PLUME CALCULATOR

TEST NO: 8
DATE OF TEST: 5/31/91
TIME OF TEST: 9:45

TEST DESCRIPTION: 50 FT BY 50 FT POOL FIRE

WIND SPEED: 1 m/sec
WIND DIRECTION: 110 degrees

FRONT VIEW CAMERA DIRECTION: 240 degrees
FRONT VIEW CAMERA DISTANCE: 3500 m
SIDE VIEW CAMERA DIRECTION: 42 degrees
SIDE VIEW CAMERA DISTANCE: 650 m

TEST LENGTH: 60 seconds
TIME STEP: 30 seconds

CHECK ALL OF THE ABOVE INFORMATION
PRESS C TO CONTINUE OR E TO EXIT PROGRAM

The initial screen displays the background data retrieved from the data file. Check the information to assure that it is correct. A capital or a small "C" will allow the user to continue. A capital or small "E" will exit the user to the operating system to make corrections in the data file.

RETRIEVING DATA

Once the test conditions have been checked, the computer will retrieve the bit maps of the two views at the first time step developed using the video program. Once all of the data have been retrieved, the user must first draw the center line of the plume on the video recorded perpendicular to the direction of the wind.

DRAW THE CENTER LINE OF THE PLUME
PRESS P TO SET A POINT
PRESS C WHEN COMPLETE OR R TO REDO CENTER LINE

Move the cursor using the arrow keys to draw the center line of the plume starting at the base of the fire. Press the letter "**P**" to set points along the center line. The computer will draw the center line as the user selects the points as shown in Fig. 6. If the center line does not look correct, press "**R**" to redraw the center line from the beginning. Press "**C**" when the center line is complete.

Fig. 6 - Centerline of the plume

Once the center line is complete, the computer will calculate the volume of the plume using a one-view approach. If the front view camera is not exactly perpendicular to the direction of the wind (plume), the image is first adjusted accordingly. The computer will determine the radius of the smoke plume at seven locations along each line segment making up the center line as shown in Fig. 7. The high and low values are neglected, and the volume of the plume at that location along the center line will be estimated by a cylinder of a length equal to the line segment length and a radius of the average of the remaining five radii. These cylindrical volumes are then added to produce the volume of the plume. The computer will display each radius/diameter as the values are calculated. The center line of the plume will also be used to calculate the trajectory of the plume.

After the single view volume and trajectory calculations are complete, the volume of the plume is then calculated using a two-view approach. If the two cameras are not at a ninety-degree angle between one another, the two values are adjusted perpendicular and parallel to the smoke plume. A set height increment (10 meters) is used to divide the plume up into equal sections. The volume is then calculated from the widths determined by the front and side cameras using the equation for the area of an ellipse and multiplying by the height increment, i.e. $V = (\pi ab)/4 * dy$, where "a" is the width of the plume from the front camera and "b" is the width from the side camera (see Fig. 7). The "dy" variable is the predetermined height increment. If the smoke plume exceeds the video screen for side view, the previously determined width is used in succeeding calculations of the plume volume and production rate through the end of the test run.

Once these two calculation techniques are complete, the results are displayed as shown in Fig. 8. The maximum height and distance may vary dramatically between two approaches. The reason for this is that the two-view approach uses the edges of the plume to determine this information while the one-view uses the center line of the plume. The user can advance to the next screen of data by entering the letter "C."

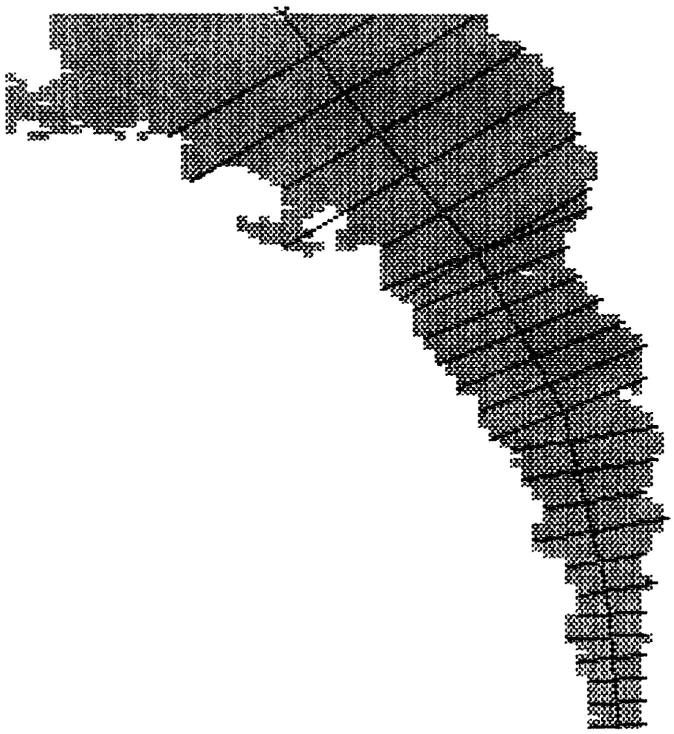
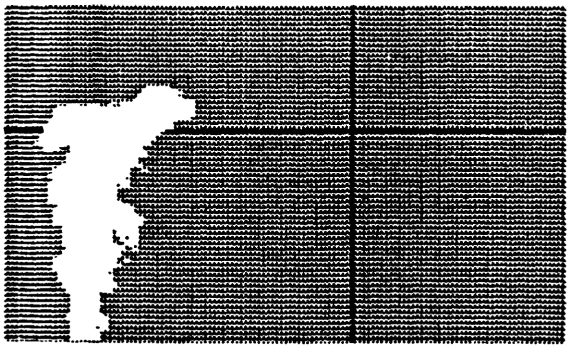


Fig. 7 - Logic used to calculate the volume in the one-view approach

TEST NUMBER : 1
ELAPSED TIME : 00:30

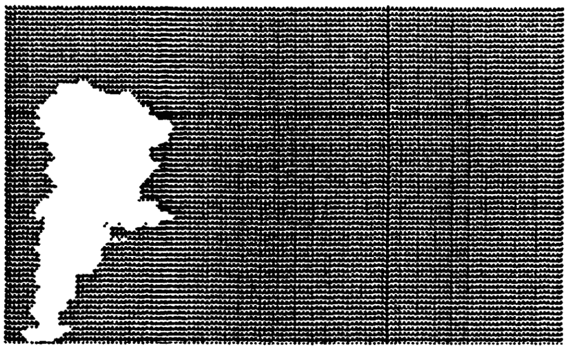
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	120	118	METERS
MAX. DISTANCE :	41	11	METERS
VOLUME OF SMOKE :	42915	44082	CU. METERS
PRODUCTION RATE :	85831	88165	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

Fig. 8 - Sample output **screen**

PLUME TRAJECTORY

COMPASS HEADING 110 degrees

DISTANCE M	HEIGHT M
0	0
0	11
0	21
1	32
1	43
1	53
1	64
2	80
5	96
8	112
11	128
14	144
17	160
17	160
21	175
24	190
28	205
32	219
35	234

This screen is a list of distances and corresponding heights which make up the trajectory of the plume. For these calculations, the model assumes the smoke is movina in the direction of the wind. The user can proceed with the program by typing in the letter "C." At this point, the process is then repeated using the bit maps produced from the next step into the fire. A summary data file is produced each time the program is run. The file is stored in ASCII format under the name SUM???.DAT (i.e. SUMO01.DAT for Test 1). A sample printout and summary data file is found in the Appendix.

SUGGESTIONS FOR INCREASED ACCURACY

- Try to capture the entire plume in both video images.

- Do not move the camera during the test.

- If conditions permit, scale the image with a height of an object over one-half the height of the screen.

- If the wind speed is very low (less than 1 m/sec), use angles parallel and perpendicular to the wind in the background data file for the location of the cameras.

- If one view is inferior due to problems with scaling or loss of the plume off the screen, rearrange the parameters in the initial data file to use the superior image as the front view/perpendicular image. This allows the center line volume calculation to be conducted using the superior view.

- If the wind speed is very low (less than 1 m/sec) and one view is inferior, use the good view for both video images.

Appendix

Sample Printout and Summary Data File

VISIBLE SMOKE PLUME CALCULATOR

TEST NUMBER : 5
DATE OF TEST : 5/28/91
TIME OF TEST : 10:00

TEST DESCRIPTION : 35 FT BY 35 FT POOL FIRE

WIND SPEED : 3.0 m / sec
WIND DIRECTION : 0 degrees

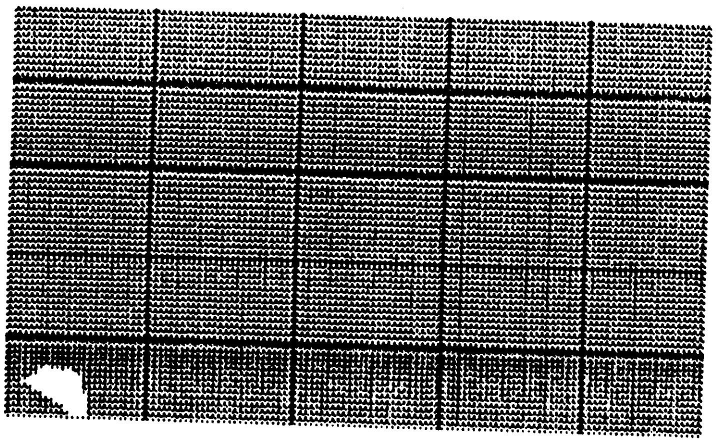
FRONT VIEW CAMERA DIRECTION : 100 degrees
FRONT VIEW CAMERA DISTANCE : 950 m
SIDE VIEW C MERA DIRECTION : 40 degrees
SIDE VIEW CAMERA >ISTANCE : 650 m

TEST LENGTH : 120 seconds
TIME STEP : 30 seconds

TEST NUMBER : 5
ELAPSED TIME : 00:30

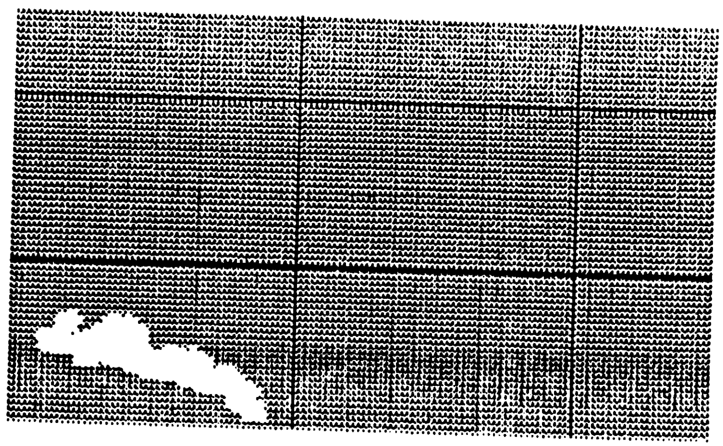
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	70	46	METERS
MAX. DISTANCE :	48	49	METERS
VOLUME OF SMOKE :	41338	73638	CU. METERS
PRODUCTION RATE :	82676	147277	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 5
ELAPSED TIME 00:30

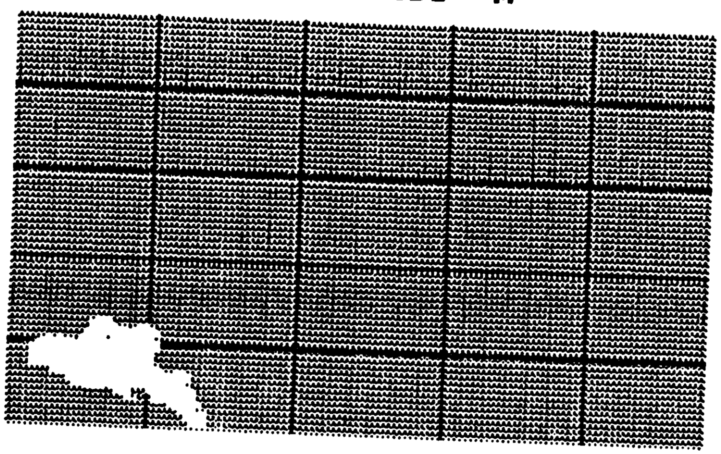
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
9.936396	8.889222
19,87281	17.9468
29.8092	27,17275
39.74561	36,56705
49.68201	46,12972

TEST NUMBER : 5
ELAPSED TIME : 01:00

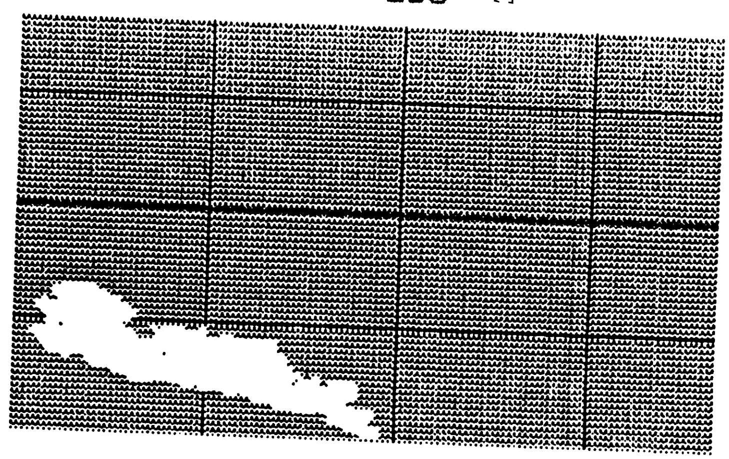
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	130	114	METERS
MAX. DISTANCE :	122	191	METERS
VOLUME OF SMOKE :	475385	541395	CU. METERS
PRODUCTION RATE :	868095	935512	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 5
ELAPSED TIME 01:00

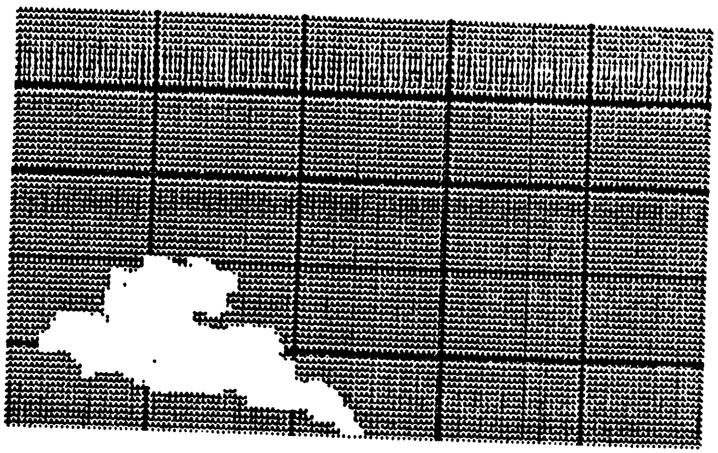
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
11.17844	8.899744
22.35688	17.98889
33.53535	27.26745
44.71379	36.73541
55.89225	46.39278
67.07063	56.23949
91.91166	67.0859
116.7527	78.35321
141.5937	90.04142
166.4347	102.1505
191.2757	114.6806

TEST NUMBER : 5
ELAPSED TIME : 01:30

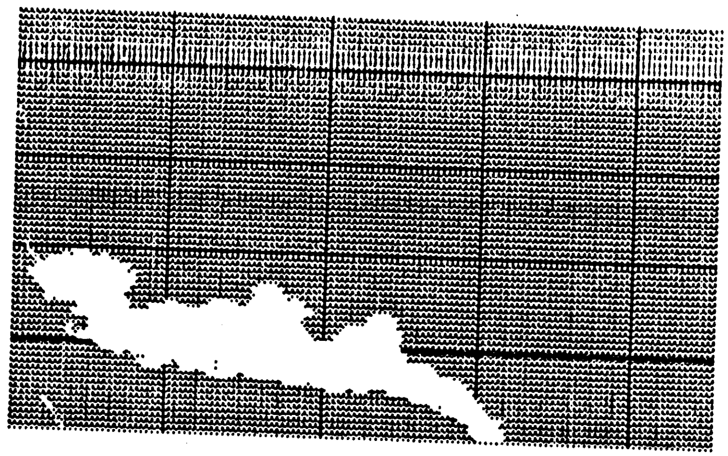
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	200	172	METERS
MAX. DISTANCE :	198	308	METERS
VOLUME OF SMOKE :	1974481	2470698	CU. METERS
PRODUCTION RATE :	2998192	3858606	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

PLUME TRAJECTORY

TEST NUMBER 5
ELAPSED TIME 01:30

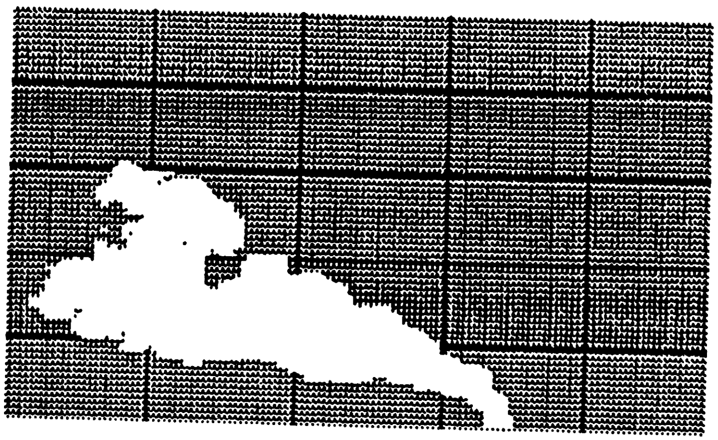
COMPASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
9.93641	7.619325
19.87276	15.38296
29.80917	23.2909
39.74558	31.34315
49.68193	39.53971
59.61834	47,88058
59.6184	47,88058
109,3004	69.50726
158.9824	92.81756
208,6644	117.8115
258.3464	144,489
308,0285	172.8501

TEST NUMBER : 5
ELAPSED TIME : 02:00

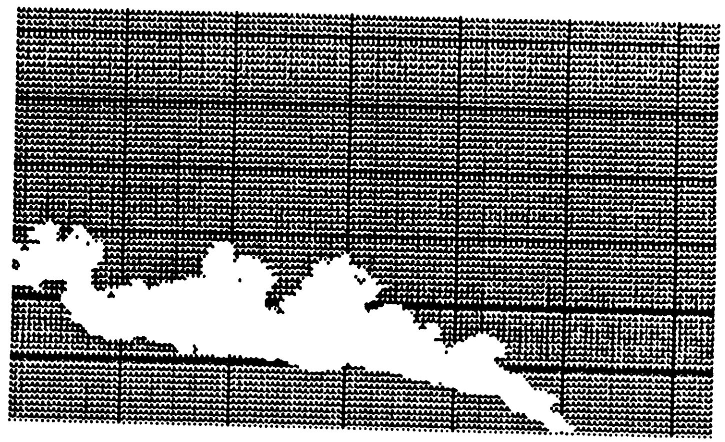
	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	310	302	METERS
MAX. DISTANCE :	350	541	METERS
VOLUME OF SMOKE :	6536319	7025034	CU. METERS
PRODUCTION RATE :	9123675	9108671	CU. METERS PER MINUTE

LINES = 100 m



CAMERA #1

LINES = 100 m



CAMERA #2

FLUME TRAJECTORY

TEST NUMBER 5
ELAPSED TIME 02:00

COMFASS HEADING 350 degrees

DISTANCE (M)	HEIGHT (M)
0	0
9.93641	10,15912
19.87282	20.51065
29.80923	31.0546
39.74564	41.79095
49,68205	52.71972
59.61834	63.84078
119.2367	81,3259
178,8551	100.2541
238,4735	120,6254
298.0919	142.4398
357,7103	165,6973
417,3284	190.3978
442,1694	211.5748
467.0104	233.3532
491,8514	255.7328
516.6924	278.7136
541.5333	302.2958

VISIBLE SMOKE PLUME CALCULATOR
TEST NUMBER : 5
DATE OF TEST : 5/28/91
TIME OF TEST : 10:00
TESTS DESCRIPTION : 35 FT BY 35 FT POOL FIRE
WIND SPEED : 3.0 m / sec
WIND DIRECTION : 0 degrees
FRONT VIEW CAMERA DIRECTION : 100 degrees
FRONT VIEW CAMERA DISTANCE : 950 m
SIDE VIEW CAMERA DIRECTION : 40 degrees
SIDE VIEW CAMERA DISTANCE : 650 m
TEST LENGTH : 120 seconds
TIME STEP : 30 seconds

ELAPSED TIME 00:30

	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	70	46	METERS
MAX. DISTANCE :	48	49	METERS
VOLUME OF SMOKE :	41338	73638	CU. METERS
PRODUCTION RATE :	82676	147277	CU. METERS PER MINUTE

PLUME TRAJECTORY

TEST NUMBER : 5
ELAPSED TIME 00:30
COMPASS HEADING 0 degrees

DISTANCE (M)	HEIGHT (M)
O	O
9.936396	8.889222
19.87281	17.9468
29.8092	27.17275
39.74561	36.56705
49.68201	46.12972

ELAPSED TIME 01: 00

	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	130	114	METERS
MAX. DISTANCE :	122	191	METERS
VOLUME OF SMOKE :	475385	541395	CU. METERS
PRODUCTION RATE :	868095	935512	CU. METERS PER MINUTE

PLUME TRAJECTORY

TEST NUMBER : 5
ELAPSED TIME 01:00
COMPASS HEADING 0 degrees

DISTANCE (M)	HEIGHT (M)
0	0
11.17844	8.899744
22.35688	17.98889
33.53535	27.26745
44.71379	36.73541
55.89225	46.39278
67.07063	56.23949
91.91166	67.0859
116.7527	78.35321
141,5937	90.04142
166,4347	102.1505
191.2757	114.6806

ELASPED TIME 01:30

	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	200	172	METERS
MAX. DISTANCE :	198	308	METERS
VOLUME OF SMOKE :	1974481	2470698	CU. METERS
PRODUCTION RATE :	2998192	3858606	CU. METERS PER MINUTE

PLUME TRAJECTORY

TEST NUMBER : 5
ELAPSED TIME 01:30
COMPASS HEADING 0 degrees

DISTANCE (M)	HEIGHT (M)
0	[illegible]
9,93641	7,619325
19.87276	15,38296
29.80917	23.2909
39.74558	31,34315
49,68193	39.53971
59.61834	47.88058
59.6184	47.88058
109.3004	69.50726
158.9824	92.81756
208.6644	117,8115
258.3464	144.489
308.0285	172.8501

ELAPSED TIME 02:00

	TWO VIEW APPROACH	CENTER LINE APPROACH	
MAX. HEIGHT :	310	302	METERS
MAX. DISTANCE :	350	541	METERS
VOLUME OF SMOKE :	6536319	7025034	CU. METERS
PRODUCTION RATE :	9123675	9108671	CU. METERS PER MINUTE

PLUME TRAJECTORY

TEST NUMBER : 5
ELAPSED TIME 02:00
COMPASS HEADING 0 degrees

DISTANCE (M)	HEIGHT (M)
0	10.15912
9.93641	
19.87282	20,51065
29,80923	31.0546
39.74564	41,79095
49.68205	52.71972
59.61834	63.84078
119.2367	81,3259
178.8551	100,2541
238.4735	120,6254
298,0919	142.4398
357,7103	165.6973
417,3284	190.3978
442,1694	211.5748
467,0104	233.3532
491,8514	255,7328
516.6924	278.7136
541.5333	302,2958

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Naval Research Laboratory - and Hughes Associates, Inc.
Washington, DC 20375 Columbia, MD 21045

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9.

10. SUPPLEMENTARY NOTES

11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.)

Interest in burning crude oil as a means to mitigate large scale oil spills at sea led to mid-scale evaluation of relevant crude oil burning characteristics. As part of this effort, a computer-based field measurement technique for estimating the size, shape, and extent of visible smoke plumes was developed. Of the experiments in which measurements were made, Test 7 provided data on plume trajectory for the largest distance from the pan. Good agreement was obtained between corresponding 35 mm photographs and digitized images used to estimate plume volume and trajectory. In Test 7, at 600 s after ignition, the leading edge of the smoke plume had risen to 750 m and traveled 1800 m downwind from the pan. The estimated total volume of the smoke plume at 600 s after ignition was 3.8×10^8 m^3. At that time, the total volume of the smoke plume was increasing at a rate of 3.2×10^6 m^3/s. Limited evaluation indicates that the MS-DOS based method provides reasonably accurate estimates of visible smoke plume geometry in the near-field. Field accuracy depends on plume size, wind speed and direction, and the resolution of the equipment.

12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS)

computer programs; crude-oil-; field models; fire tests; pattern recognition; smoke plumes; wind velocity

13. AVAILABILITY

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